

Targeted Neuroplasticity Training (TNT)

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Cognitive-skill training is vital part of fulfilling national security mission

TNT Goal: Faster, more effective cognitive training for a variety of DoD applications

DoD applications of interest to the TNT program include, but are not limited to:



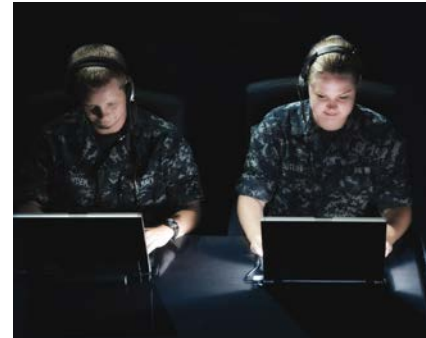
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Tactical Operations Center
(TOC)



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Foreign Language



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Cryptography



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Intelligence



TNT – enhancing cognitive skill learning

Vision: enhancing cognitive skill learning in healthy adults by using noninvasive peripheral neurostimulation to promote synaptic plasticity in the brain

Cognitive Training Protocols

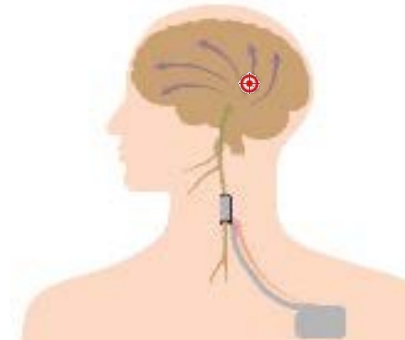


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Engage task-specific brain regions

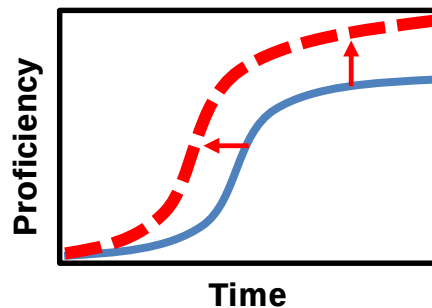


Peripheral Nerve Stimulation



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Engage neuromodulatory circuitry

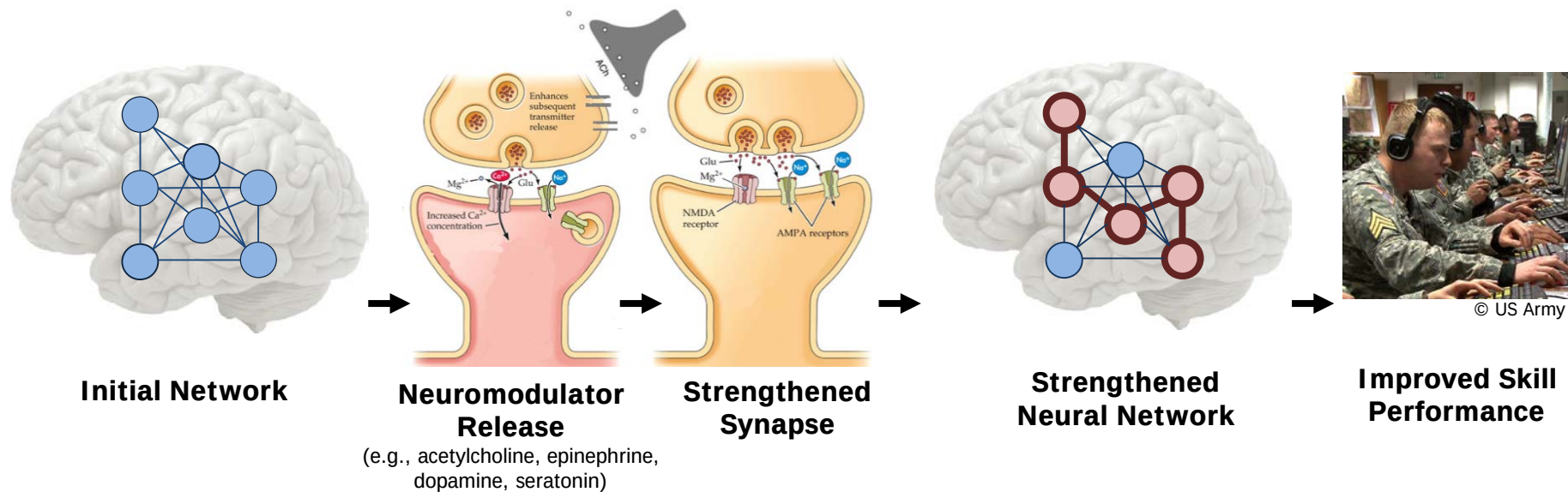


Result:

Train personnel **faster** & with **superior** cognitive abilities



Skill learning and the brain

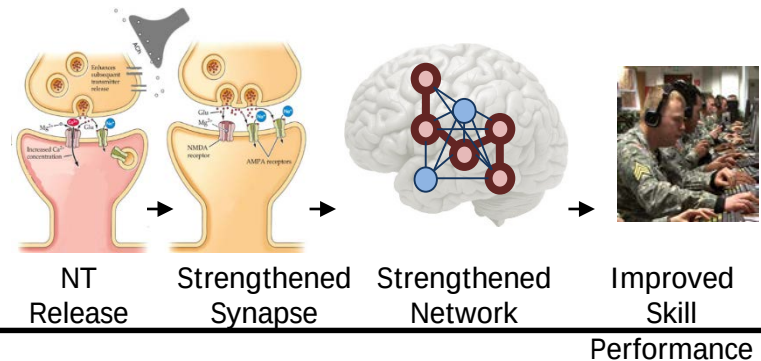




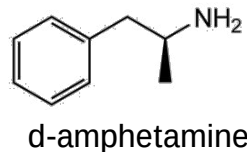
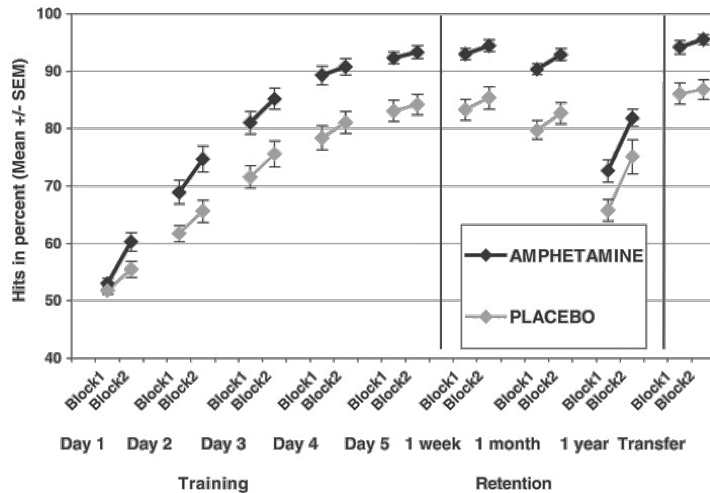
Skill learning and the brain

Pharmaceuticals

Enhances Learning?	Specific?	Invasive?	Side Effects?
Mixed - Some agents promote learning under specific circumstances	No	No	Yes, such as addiction, cardiac, and respiratory effects

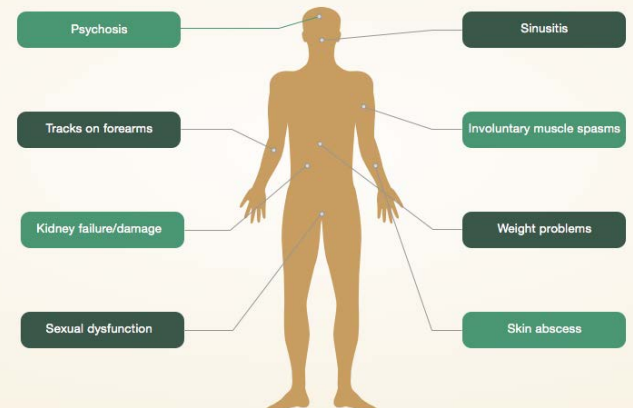


Language transfer from visual to spoken material



Amphetamine Long-Term Effects

Abusing amphetamines over a long period of time can cause many mental and physical problems.



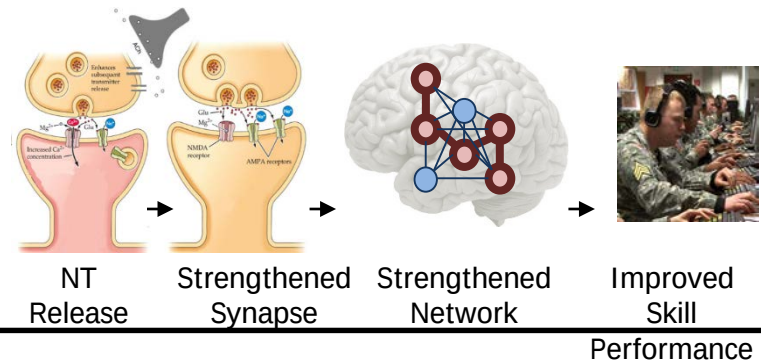
Breitenstein et al., 2004



Skill learning and the brain

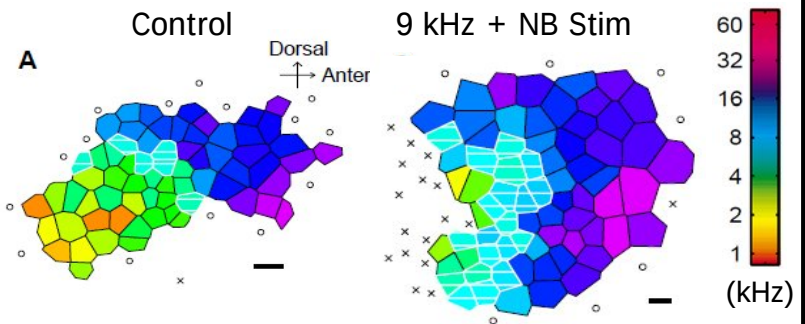
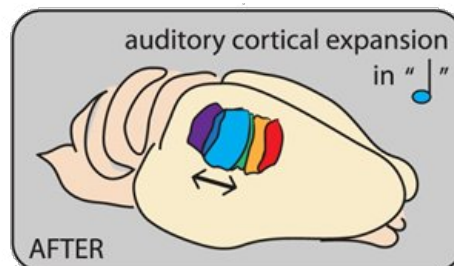
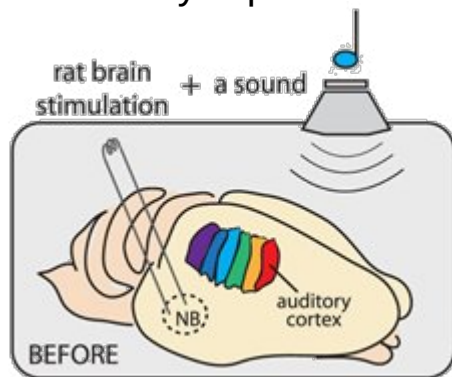
Deep Brain Stimulation

Enhances Learning?	Specific?	Invasive?	Side Effects?
Yes	Specificity depends on device	Requires implantation into brain	Surgical complications, off-target effects



Paired Brain Stimulation and Sensory Exposure:

Increased representation of paired tone in auditory cortex:



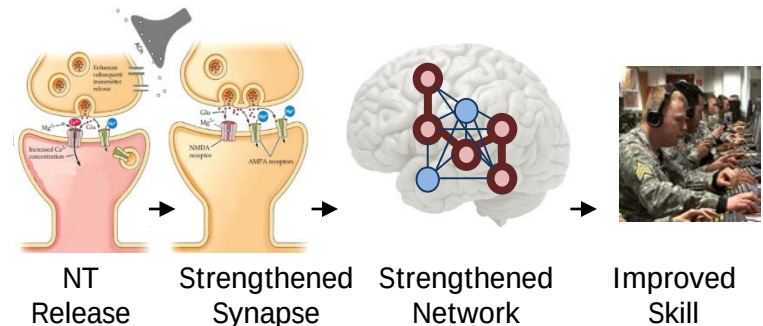
Kilgard et. Al., 1998



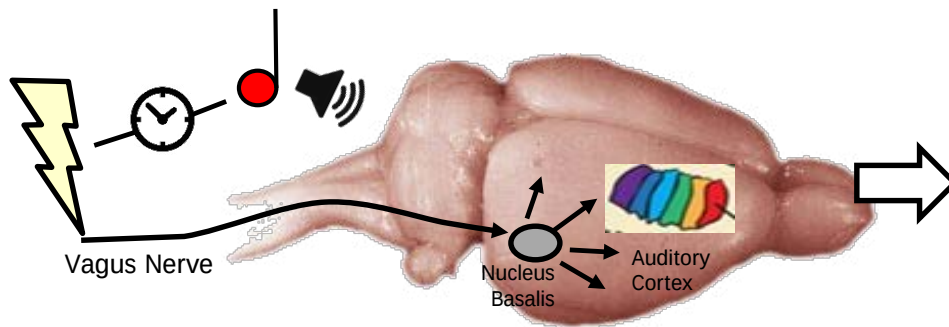
Skill learning and the brain

Invasive PNS Stimulation

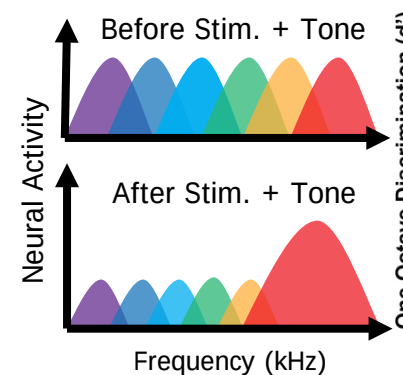
Enhances Learning?	Specific?	Invasive?	Side Effects?
Yes	Yes	Yes	Yes, minor



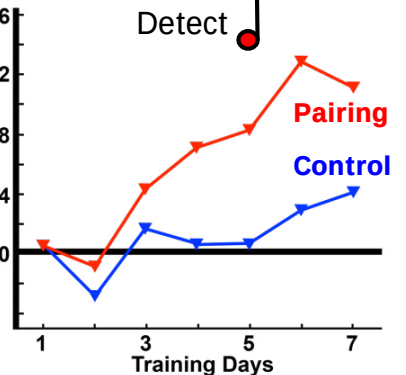
Paired Nerve Stimulation and Sensory Exposure:



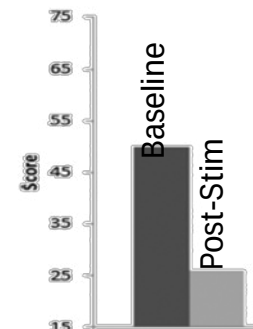
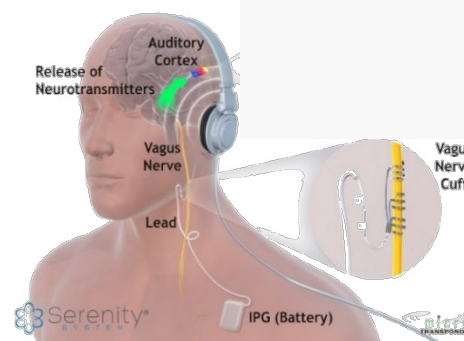
Neural Changes:



Behavioral Improvement:



Tinnitus Rehab in Humans:

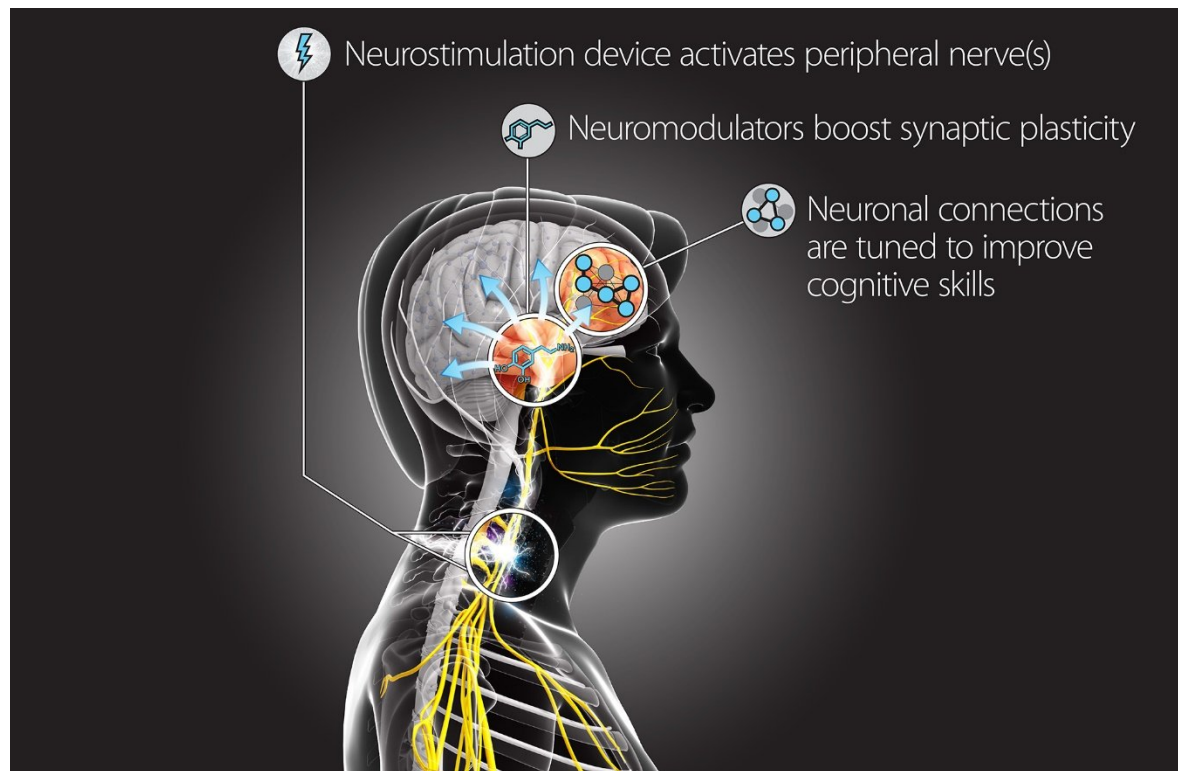
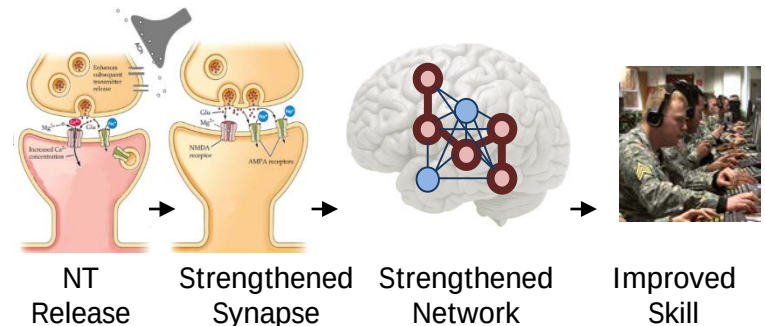




Skill learning and the brain

Training + Non-Invasive PNS Stimulation

Enhances Learning?	Specific?	Invasive?	Side Effects?
Yes	Yes	No	No





General Objectives

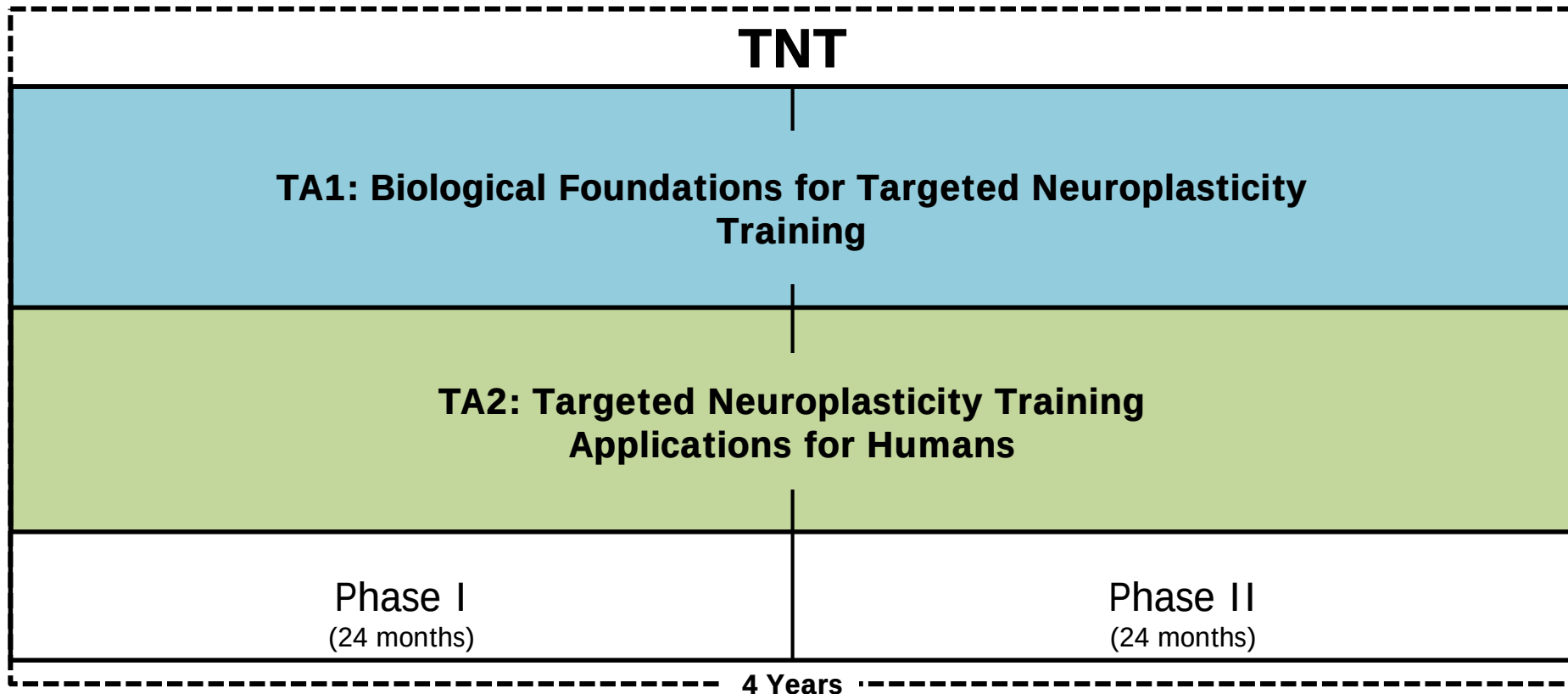
- 1) Elucidate the anatomical and functional map(s) of the peripheral and central nervous system circuitry that regulates synaptic plasticity in the brain
- 2) Demonstrate effects of peripheral neurostimulation on cognitive skills and the brain activity supporting those skills
- 3) Optimize noninvasive stimulation methods and training protocols for long-term retention without negative side effects

By the end of the 4-year TNT program:

Demonstrate that targeted neuroplasticity training methods yield at least a
30 % improvement in learning rate and/or skill performance
with minimal negative side effects



Program Structure



TNT goal: Demonstrate that targeted neuroplasticity training methods yield at least a **30 % improvement in learning rate and/or skill performance** with minimal negative side effects

End-of-Phase goals set by DARPA (see BAA and following slides)
Intermediate milestones set by performer and should be identified within proposal



TA1: Biological Foundations for Targeted Neuroplasticity Training

TA1 Primary objective: perform hypothesis-driven research to measure and demonstrate effects of peripheral neurostimulation in promoting plasticity, and assess quantitative changes in neurophysiology and behavior

Phase I Goals	
Research Objectives	Milestones and Deliverables
Demonstrate that peripheral neurostimulation promotes synaptic plasticity by measuring changes in neural activity and neurochemicals in brain.	Provide data validating proposed hypotheses regarding functional and anatomical map(s) of circuitry between peripheral nerve and CNS structures. Input/output response profiles for peripheral neurostimulation and plasticity modulation in CNS.
Demonstrate acute effects of targeted neuroplasticity training on brain neurophysiology and learning rate and/or skill performance at least 15% greater than control.	Provide data demonstrating quantified changes in task performance (e.g., accuracy, speed) and neural network physiology (e.g., neural tuning functions and functional connectivity) with training.
Test for off-target effects of peripheral neurostimulation and training.	Provide stimulation parameter map for identified side effects.



TA1: Biological Foundations for Targeted Neuroplasticity Training

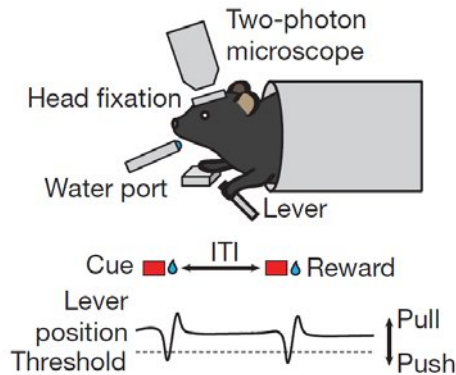
TA1 Primary objective: perform hypothesis-driven research to measure and demonstrate effects of peripheral neurostimulation in promoting plasticity, and assess quantitative changes in neurophysiology and behavior

Phase II Goals	
Research Objectives	Milestones and Deliverables
Demonstrate chronic effects of targeted neuroplasticity training on neurophysiology and learning rate and/or skill performance at least 30% greater than control, including measures of long-term retention of trained skills.	Provide data demonstrating quantified changes in task performance (e.g., accuracy, speed) and neural network physiology (e.g., neural tuning functions and functional connectivity) over training periods that span days or weeks and retention evaluated >30 days after training.
Optimize stimulus protocols in animal models to minimize negative side effects.	A peripheral neurostimulation and training protocol that exhibits minimal side effects in animal models.

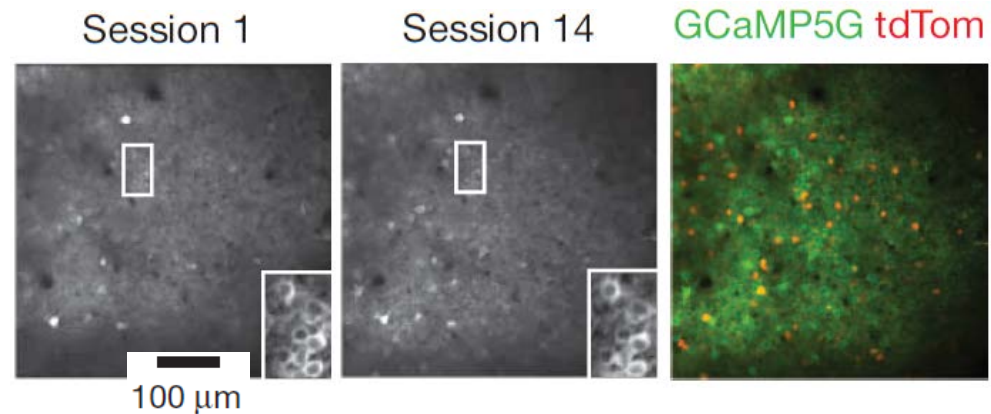


Large-scale neural recording and learning studies

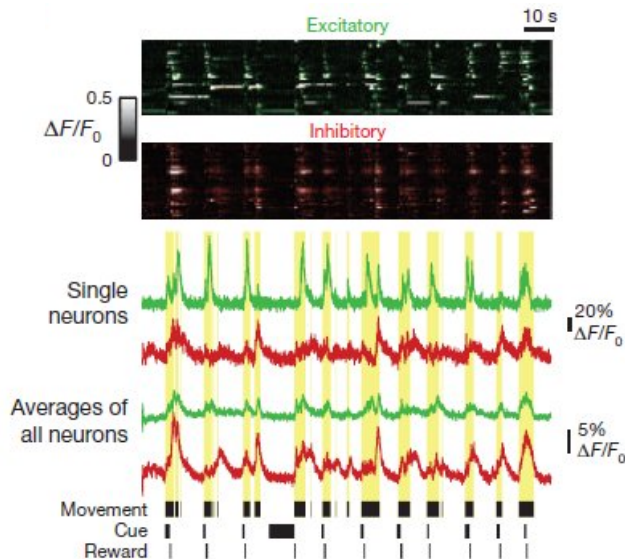
Motor learning task



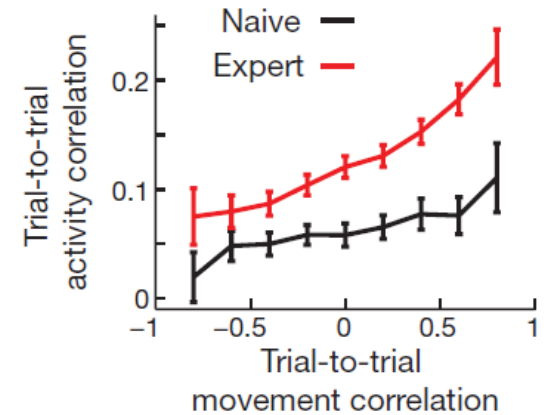
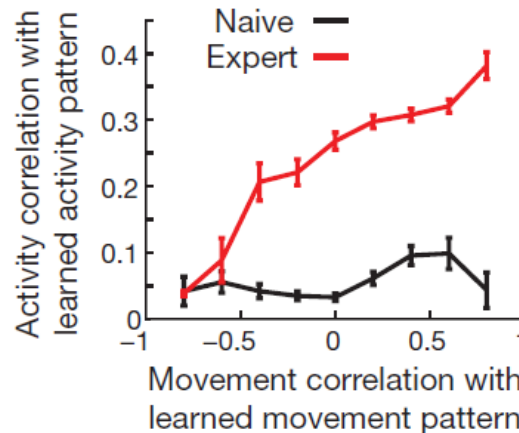
Calcium imaging of neurons in motor cortex



Analysis of neuronal activity



Coordinated evaluation of neuronal activity and task learning



Peters et. al., Nature 2014



TA2: Targeted Neuroplasticity Training Applications for Humans

TA2 Primary objective: Develop, demonstrate, and validate cognitive-skill training applications for humans that leverage noninvasive peripheral neurostimulation to promote synaptic plasticity.

Phase I Goals	
Research Objectives	Milestones and Deliverables
Identify mechanisms for modulating neuroplasticity in humans with noninvasive peripheral neurostimulation devices.	Provide data validating proposed hypotheses regarding specific peripheral nerve targets for stimulation and effects on synaptic plasticity, brain function, and learning rates.



TA2: Targeted Neuroplasticity Training Applications for Humans

TA2 Primary objective: Develop, demonstrate, and validate cognitive-skill training applications for humans that leverage noninvasive peripheral neurostimulation to promote synaptic plasticity.

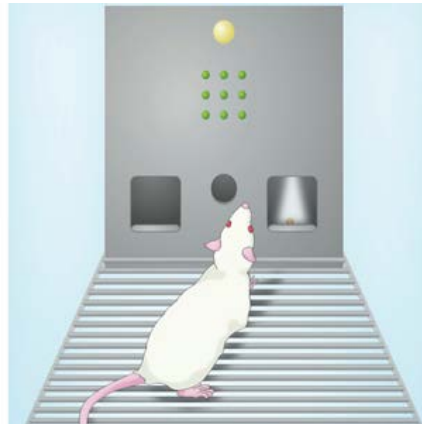
Phase II Goals	
Research Objectives	Milestones and Deliverables
Refine peripheral neurostimulation and training protocols to ensure easy and reliable operation with minimal negative side effects.	A peripheral neurostimulation device and training protocol with reliable indicators of target nerve engagement and empirical data demonstrating minimal side effects on physical and cognitive functions.
Evaluate benefits of targeted neuroplasticity training with goal of demonstrating learning rate and/or skill performance at least 30% above control.	Provide performance data from randomized, controlled study comparing learning rates and retention between targeted neuroplasticity training and unstimulated controls.



Program Structure

Performer responsibility:

Demonstrate that your approach reduces training time in a lab setting



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DARPA responsibility:

Find appropriate DoD partners to pursue implementation in the field



© US Army



Scope

	IN SCOPE	OUT OF SCOPE
Stimulation Approach	Technologies targeting the peripheral nervous system	Technologies targeting the central nervous system (including, but not limited to, tDCS, tACS, tRNS, TMS, DBS)
Targeted Skills	Perception, comprehension, decision making, motor control, and many others	Memory
Application space	DoD-relevant training in healthy adults (including, but not limited to, foreign language learning, TOC control, intelligence analysis, cryptography)	Rehabilitation and other clinical applications

Use of **NONINVASIVE** technologies is required.
Use of **INVASIVE** technologies for comparison is encouraged.

Use of **COTS technology** is expected. Development of novel devices is discouraged.



Proposals and Teaming

- Proposal Due Date: **June 2, 2016**
- Proposals must address TA1 and TA2 **in full**

Teaming

It is anticipated that teaming will be necessary to cover the wide range of animal and human tasking required in this program

Tips:

- 1) Listen to presenters during today's "intro blitz" sessions, where attendees will briefly present their expertise and capabilities
- 2) Utilize the TNT teaming website: <https://team.sainc.com/TNT/home.aspx>.
- 3) Reach out to colleagues and collaborators



BAA Inbox and FAQ

- Direct **ALL** questions and communication to the BAA Inbox
 - DARPA-BAA-16-24@darpa.mil
 - Dr. Weber, any member of his team, or any member of the scientific review panel will not **directly communicate** with a potential proposer regarding BAA-16-24; all communication will be conducted through the BAA Inbox
 - Dr. Weber and the BAA Inbox cannot provide feedback or guidance on any aspect of your proposal, they can only clarify the content of BAA-16-24
- BAA Inbox FAQ
 - DARPA will post a consolidated FAQs on a regular basis
 - To access the posting go to:
 - <https://www.fbo.gov/spg/ODA/DARPA/CMO/DARPA-BAA-16-26/listing.html>
 - Submit your question(s) by E-mail to DARPA-BAA-16-24@darpa.mil at least 15 days before the proposal submission deadline



Advice

- Read the BAA, carefully – and respond accordingly.
 - Some instructions are specific – “required” and “must”
 - Most of the instructions are non-specific – you decide on what is the best possible science to support the objectives of the program
 - Be honest about risks and demonstrate thoughtful consideration for how to mitigate those risks.
- Ask for clarification as needed. FAQs will be updated regularly.
- Take advantage of today’s opportunities to meet potential teammates and ask questions



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OFFICE OF THE UNDER SECRETARY OF DEFENSE
(COMPTROLLER)
CHIEF FINANCIAL OFFICER

FEBRUARY 2016

CORRECTION: PAGE 1-5 (2-9-2016)



DEFENSE BUDGET
OVERVIEW

UNITED STATES DEPARTMENT OF DEFENSE FISCAL
YEAR 2017 BUDGET REQUEST



Preface

The Overview Book has been published as part of the President's Annual Defense Budget for the past few years. From FY 1969 to FY 2005, OSD published the "Annual Defense Report" (ADR) to meet 10 USC Section 113 requirements. Subsequently, the Overview began to fill this role.

The Overview is one part of an extensive set of materials that constitute the presentation and justification of the President's Budget for FY 2017. This document and all other publications for this and previous DoD budgets are available from the public web site of the Under Secretary of Defense (Comptroller): www.comptroller.defense.gov.

The Press Release and Budget Briefing, often referred to as the "Budget Rollout," and the Program Acquisition Costs by Weapons System book, which includes summary details on major DoD acquisition programs (i.e., aircraft, ground forces programs, shipbuilding, space systems, etc.) are especially relevant.

The website for Performance Improvement tables and charts is <http://dcmo.defense.gov/Publications/AnnualPerformancePlanandPerformanceReport.aspx>.

Other background information can be accessed at www.defense.gov.

The estimated cost of this report or study for the Department of Defense is approximately \$28,000 for the 2016 Fiscal Year. This includes \$12,000 in expenses and \$16,000 in DoD labor.

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Table of Contents

1. FY 2017 Budget Summary	1-1
Seek a Balanced Force	1-2
Manage Enduring Readiness Challenges	1-3
Accelerate the Pace of Defense Reform	1-3
Pursue Investments in Military Capabilities	1-3
Take Care of Our People	1-4
Support Overseas Contingency Operations	1-4
FY 2017 – FY 2021 Topline	1-5
2. Seek a Balanced Force	2-1
Security and Fiscal Environments	2-1
The Defense Strategy	2-1
Balance the Joint Force	2-2
Supporting Personnel	2-4
3. Manage Enduring Readiness Challenges	3-1
Generating Service Capabilities	3-2
Generating Joint Capabilities	3-13
4. Accelerate the Pace of Defense Reform	4-1
Force Structure for Current and Future Operations	4-2
Base Realignment and Closure	4-2
Health Care Reform	4-2
Infrastructure and Support Activity Reforms	4-3
Better Buying Power: Obtaining Greater Efficiency and Productivity in Defense Spending ..	4-4
Control Costs throughout the Product Life Cycle	4-5
Financial Improvement and Audit Readiness Initiative	4-6
Audit and Contract Management Oversight	4-7
Improving the Financial Management Workforce	4-8
5. Pursue Investments in Military Capabilities	5-1
Space and Space-Based Systems	5-3
Missile Defense Programs	5-4
Cyberspace Operations	5-5
Science & Technology	5-6

Overview – FY 2017 Defense Budget

6. Take Care of Our People	6-1
Military Compensation	6-3
Blended Retirement System	6-6
Force of the Future	6-8
Managing the Military Health System.....	6-9
Strengthening Military Families	6-15
Supporting DoD Civilians	6-17
7. Support Overseas Contingency Operations	7-1
Summary	7-1
Force Level Budget Assumptions	7-2
Overseas Contingency Operations Budget Request	7-3
Iraq Train and Equip Fund	7-5
Syria Train and Equip Fund	7-6
Counterterrorism Partnerships Fund	7-6
European Reassurance Initiative	7-7
8. Military Departments	8-1
Army	8-1
Navy/Marine Corps	8-11
Air Force	8-17
9. Performance Improvement	9-1
Appendix A. Resource Exhibits	A-1
Table A-1 Combat Force Structure Overview	A-1
Table A-2 Active Component End Strength – Base Budget	A-2
Table A-3 Active Component End Strength – OCO Budget	A-2
Table A-4 Active Component End Strength – Base + OCO Budget	A-2
Table A-5 Reserve Component End Strength	A-3
Table A-6 DoD Base Budget by Appropriation Title	A-3
Table A-7 DoD Base Budget by Military Department	A-3
Table A-8 DoD OCO Budget by Appropriation Title	A-4
Table A-9 DoD OCO Budget by Military Department	A-4
Table A-10 DoD Total Budget by Appropriation Title	A-4
Table A-11 DoD Total Budget by Military Department	A-5
Table A-12 DoD Base Budget by Military Department and Appropriation Title	A-5

Overview – FY 2017 Defense Budget

Table A-13 DoD OCO Budget by Military Department and Appropriation Title A-6

Table A-14 DoD Total* Budget by Military Department and Appropriation Title A-8

Appendix B. Acronym List

B-1

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1. FY 2017 BUDGET SUMMARY

The Fiscal Year (FY) 2017 budget submission complies with the Bipartisan Budget Act of 2015 and sustains the alignment of program priorities and resources with the 2014 Quadrennial Defense Review (QDR) and supports military operations in Afghanistan and other areas of the world to counter threats from terrorists. The updated defense strategy, as set forth in the QDR, is right for the nation, sustaining the global leadership role of the United States and providing the basis for decisions that will help bring the military into balance over the next decade and responsibly position the Department for an era of both strategic and fiscal uncertainty. The geopolitical developments of the last year have only reinforced the need to adequately resource the Department

of Defense (DoD). The Department's response to recent events, which include the Islamic State of Iraq and the Levant (ISIL) offensive into Iraq and Syria, the Russian Federation's aggressive acts and attempts to intimidate neighboring countries, China's continued anti-access military modernization programs and its island-building and sovereignty claims in international waters, as well as high-profile cyberattacks, have placed additional pressures on DoD that would be extremely difficult to resource should the Department be forced to return to sequester level funding after FY 2017.

The FY 2017 budget request is designed to protect capabilities that are most closely aligned with the defense strategy's objectives to protect the homeland, build security globally, and project power and win decisively. The budget also maintains a ready force, continues to take care of service members and their families, extends enterprise reforms that control costs, and seizes opportunities to build the future force by developing new and innovative operational concepts and dominating technological frontiers including undersea, cyber, space, electronic warfare, and other advanced capabilities. In developing the FY 2017 budget and planning for future years, the Department supports progress toward achieving and maintaining full-spectrum combat readiness by all four Military Departments.

It is important to note that the FY 2017 budget request and the enacted FY 2016 budget come after several years of declining defense budgets. This defense drawdown, which began with the FY 2010 budget, was the fifth major defense drawdown since the end of World War II (WWII), following those after WWII and the Korean War, the Vietnam War, and the Cold War. While this decline largely reflects a significant drawdown of U.S. presence in Iraq and Afghanistan, it occurred in a period of considerable instability and was driven to a substantial extent by the restrictions of the Budget Control Act (BCA) of 2011 rather than by strategic considerations.

With continuing fiscal and strategic uncertainty, the FY 2017 budget request reflects the Department's responsible choices to develop a coherent defense program with the proper balance between capacity, capabilities, and current and future readiness. The FY 2017 funding levels will allow the military to protect and advance U.S. interests and execute the updated defense strategy — but with somewhat increased levels of risk for some missions. The Department will continue to experience gaps in training and maintenance over the near term and will have a reduced margin of error in dealing with risks of uncertainty in a dynamic and shifting security environment over the long term. As a global leader, the United States requires a robust national defense strategy to protect and advance its interests, and ensure the security

Key Themes

- Seek a Balanced Force
- Manage Enduring Readiness Challenges
- Accelerate the Pace of Defense Reform
- Pursue Investments in Military Capabilities
- Take Care of Our People
- Support Overseas Contingency Operations

Overview – FY 2017 Defense Budget

of its allies and partners, with a military that can implement that strategy effectively. This goal can only be achieved by the package of balanced reforms and initiatives that the Department is presenting to Congress and will require partnership between Congress and DoD to make politically difficult choices. Most importantly, the specter of sequestration needs to be eliminated. The nation's defense strategy cannot be executed at sequester-levels of funding.

For FY 2017, the Department is requesting a total of \$582.7 billion, which is \$2.4 billion (about 0.4 percent) more than the FY 2016 enacted level of \$580.3 billion, to finance base and overseas contingency operations. The FY 2017 base budget provides \$523.9 billion, an increase of \$2.2 billion from the FY 2016 enacted budget of \$521.7 billion, and is consistent with the Bipartisan Budget Act of 2015. It reflects Administration-wide efforts to make tough program choices. This budget adjusts programs that support joint force technological superiority, stabilizes total ground force end strength, funds important reforms of health care, retirement, and family programs, focuses on building the force of the future, and continues to make better use of defense resources through acquisition reform, management reform, and reducing lower priority programs to comply with the Bipartisan Budget Act.

The Department is also requesting that the Congress provide the authority that would permit the Department to conduct another round of Base Realignments and Closure to reduce unneeded facilities and repurpose scarce defense resources from maintaining this unneeded infrastructure to higher national security priorities.

The FY 2017 Overseas Contingency Operations (OCO) budget is \$58.8 billion. This request will enable the Department to maintain a U.S. presence in Afghanistan consistent with the President's drawdown plan, sustain personnel forward deployed to the Middle East to conduct a range of operations alongside a robust international coalition to degrade and defeat the Islamic State of Iraq and the Levant (ISIL), build the capacity of the Iraqi and Syrian opposition forces to counter ISIL in Iraq and Syria; support partner nations in counterterrorism efforts; and enhance the U.S. presence in Eastern Europe to assure allies and deter aggressive actors in the region.

Figure 1-1. Department of Defense Budget

<i>\$ in billions</i>	FY 2015 Actual	FY 2016 Enacted	FY 2017 Request	FY16 – FY17 Change
Base	497.3	521.7	523.9	+2.2
OCO	63.1	58.6	58.8	+0.2
Total	560.4	580.3	582.7	+2.4

Discretionary budget authority

Numbers may not add due to rounding

The overall themes developed in this overview are explained in the following chapters:

- Seek a Balanced Force (Chapter 2)
- Manage Enduring Readiness Challenges (Chapter 3)
- Accelerate the Pace of Defense Reform (Chapter 4)
- Pursue Investments in Military Capabilities (Chapter 5)
- Take Care of Our People (Chapter 6)

In addition, Chapter 7 summarizes the FY 2017 request to support Overseas Contingency Operations, Chapter 8 provides views of each of the Department's Military Services, and Chapter 9 provides performance improvement information.

SEEK A BALANCED FORCE

For much of the past decade, the DoD focused on fighting terrorism and countering violent insurgencies. The Department will continue the fight as long as these threats exist. But the security environment is rapidly changing as warfare evolves across all domains. The defense strategy outlined in the 2014 QDR and supported in this budget focuses on a Joint Force with the ability to simultaneously protect the homeland; provide a global presence in support of U.S. interests; and project power against a range of adversaries and challenges across the spectrum of conflict.

The FY 2017 budget request is consistent with the FY 2016 budget request in planning to adjust the size of the force over the next several years to a level of 980,000 soldiers, 308 ships, 182,000 active-duty Marines, and 55 Air Force tactical fighter squadrons. The budget continues to make informed choices to achieve a modern, ready, and balanced force to meet the full range of potential military missions. The restructured force will sustain its technological edge, be capable of deterring and, if necessary, defeating aggression, and improve its readiness to accomplish key missions.

This budget will protect basic and applied research to ensure the United States maintains its technological edge. The Administration emphasizes a strong national investment in research and development, emphasizing science and technology that is vital to our future competitive advantage.

MANAGE ENDURING READINESS CHALLENGES

The 2014 QDR highlights the importance of and commitment to maintaining ready and capable forces. Readiness investments in equipment maintenance, exercises, and training technologies are necessary complements to investments in military capabilities. Today U.S. forces are postured globally, conducting counterterrorism, stability, and deterrence operations, maintaining a stabilizing presence, conducting bilateral and multilateral training to enhance U.S. security relationships, and providing the crisis response capabilities required to protect U.S. interests. This budget supports the Military Departments' continued reemphasis on full-spectrum readiness that began with the FY 2014 budget. The investments made in full-spectrum readiness will yield a smaller but more ready force, prepared to achieve its missions anywhere at any time required.

ACCELERATE THE PACE OF DEFENSE REFORM

The Department is seizing opportunities to redirect resources by reducing management headquarters and overhead, attracting the best talent, emphasizing technological superiority in acquisitions to achieve dominant capabilities, restructuring weapons programs, and consolidating infrastructure.

The Department has learned from prior drawdowns that it is impossible to generate all the needed savings just through efficiencies. The Department prioritizes by focusing on key missions relevant to the future security environment. The Department also has learned that excess, unneeded facilities and infrastructure must be eliminated. The Department is wasting scarce defense resources on maintaining facilities that far exceed DoD's needs. The Congress must provide the Department with the authority to pursue another Base Realignment and Closure round beginning in FY 2019. As the Department draws down to a smaller, more capable, agile force, it must eliminate all areas of waste to include maintaining unneeded facilities.

Overview – FY 2017 Defense Budget

This budget continues and expands the reform agenda advanced in the previous five budgets, with ever-increasing emphasis on enhancing how DoD does business. The Department must continue to reduce the “cost of doing business” to maximize the availability of its constrained resources for the optimum balance of force structure capacity and technological capabilities. This includes divesting lower priority or excess force structure and excess infrastructure as well as compensation changes.

PURSUE INVESTMENTS IN MILITARY CAPABILITIES

In support of the defense strategy, the FY 2017 President’s Budget emphasizes the capabilities needed to modernize the force for a wide range of missions, including the ability to project power against advanced adversaries. The Department’s investments in technologically advanced weaponry are designed to yield a military force that achieves the nation’s security objectives and ensure that the United States remains a technologically superior global force to promote peace and security. In addition, the Defense Innovation Initiative (DII) is a Department-wide effort to identify and invest in unique ways to advance U.S. military superiority for the 21st century, including investments in: 1) a long-range research and development program designed to identify new technologies and their uses; 2) innovative leadership; 3) war-gaming; 4) operational concepts; and 5) innovative business practices.

The FY 2017 budget request continues to give prominence to the improved lethality, survivability, sustainability, and affordability of the next generation of weapons systems and military equipment. The budget also protects key capability areas in support of DoD’s strategy, including nuclear deterrence; space-based systems; power projection; missile defense; cyber defense; intelligence, surveillance, and reconnaissance; and counter terrorism and special operations.

TAKE CARE OF OUR PEOPLE

America asks much of its All-Volunteer Force (AVF) and the civilians who support that force. The Department of Defense (DoD) must preserve the quality of its most prized asset, the AVF, which is comprised of high quality, educated, motivated personnel who are committed to excellence in defense of the Nation. Therefore, this budget keeps faith with the men and women in uniform and their families, because the volunteer force is central to a strong future military.

Personnel costs, including military pay and allowances, military health care, civilian pay, and family support, encompass nearly half of the Department’s budget. The FY 2017 budget request continues to take care of DoD’s people and their families while addressing costs in a responsible manner. The Department provides a strong package of pay and benefits that is balanced with readiness, capacity, and the capabilities needed to execute the national defense strategy. In fact, military pay and benefits continue to increase on a per-capita basis. Given the sharp growth in military compensation, such as medical costs that have more than doubled since 2001, the Department is taking steps again in the FY 2017 budget request to maintain balance in the rate of growth in military pay and health care costs. The Department is also implementing new reforms in military retirement, child care policies, and maternity and paternity leave to adapt our policies to meet the needs of today’s service members as well as the force of the future.

SUPPORT OVERSEAS CONTINGENCY OPERATIONS

The FY 2017 President’s budget includes \$58.8 billion for overseas contingency operations (OCO) including Operation FREEDOM’S SENTINEL (OFS) in Afghanistan, Operation

Overview – FY 2017 Defense Budget

INHERENT RESOLVE (OIR) in Iraq and the Levant, increasing efforts to support European allies and deter aggression, and supporting a partnership-focused approach to counterterrorism.

FY 2017 – FY 2021 TOPLINE

The historical funding picture is summarized in Figure 1-2:

Figure 1-2. Department of Defense Topline Since September 11th Attacks

(\$ in billions)	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
Base	287.4	328.2	364.9	376.5	400.1	410.6	431.5	479.0	513.2
OCO	22.9	16.9	72.5	90.8	75.6	115.8	166.3	186.9	145.7
Other*	5.8	--	--	0.3	3.2	8.2	3.1	--	7.4
Total	316.2	345.1	437.5	467.6	478.9	534.5	600.9	665.9	666.3

(\$ in billions)	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017
Base	527.9	528.2	530.4	495.5	496.3	497.3	521.7	523.9
OCO	162.4	158.8	115.1	82.0	84.9	63.0	58.6	58.8
Other*	0.7	--	--	0.1	0.2	0.1	--	--
Total	691.0	687.0	645.5	577.6	581.4	560.4	580.3	582.7

*Other non-war supplemental funding

Numbers may not add due to rounding

Figure 1-3 presents the proposed FY 2017 – FY 2021 DoD base budget topline for this year's President's budget, as compared to last year's FY 2016 President's budget.

Figure 1-3. DoD Proposed Outyear Topline for the Base Budget

Current \$ in Billions	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY17-FY21 TOTAL
FY 2016 PB	547.3	556.4	564.4	570.0	581.4	2,819.5
Change	-23.4	0.3	0.5	0.4	3.8	-18.5
FY 2017 PB	523.9	556.7	564.8	570.4	585.2	2,801.1
CORRECTION: (2-9-2016)						
FY17 PB % Real Change	-1.1%	+4.2%	-0.5%	-1.0%	+0.5%	+0.4%

*Average annual real growth of the FY 2017 President's Budget for FY 2017-FY 2021.

Numbers may not add due to rounding.

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2. SEEK A BALANCED FORCE

This chapter provides an overview of how the FY 2017 budget request supports the defense strategy through its investments to balance modernization, force structure, and readiness for the current and future Joint Force in the face of a dynamically evolving security environment.

Seek a Balanced Force

- Security and Fiscal Environments
- The Defense Strategy
- Balance the Joint Force
- Supporting Personnel

SECURITY AND FISCAL ENVIRONMENTS

The United States continues to face a rapidly changing security environment, as warfare evolves across all domains. The Department must maintain ready forces with superior capabilities to deter potential adversaries and defeat attacks across the full spectrum of conflict and address a wide range of security challenges. The nation faces emerging challenges in particular from Russia and China, who continue to develop military systems and doctrine that could erode traditional U.S. military advantages in specific areas, as well as continuing challenges and threats from potential regional aggression posed by Iran and North Korea. The nation will also continue to confront terrorists around the globe, most immediately in Iraq and Syria as part of operations to counter the Islamic State in Iraq and the Levant (ISIL). Thus, the Department's strategic approach to resourcing and developing the Joint Force must be to ensure its ability to deter aggression posed by these priority threats while continuing to prosecute counter-terrorism operations. The Department's budget must enable the Joint Force to fight and win today while simultaneously prioritizing and protecting its capability and readiness to ensure the United States can fight and win in possible future conflicts.

However, the Department is still recovering from years of fiscal reductions and instability. The Bipartisan Budget Act of 2015 provided the Department with an FY 2016 base budget that grew by \$26 billion, the largest increase during this Administration, and also provided some funding stability for FY 2017, although in both cases the Department received fewer resources than required. As a result of this agreement, the Department can make key investments to address priority threats. However, unless Congress acts, annual sequestration cuts are set to return after FY 2017. To protect the nation's security interests within the constraints imposed by the national imperative to reduce the deficit, and to maintain the U.S. military's competitive advantages in facing future threats, the FY 2017 budget request proposes a Defense base budget of \$523.9 billion. The base budget request is approximately \$2.2 billion above the Department's FY 2016 enacted appropriations.

THE DEFENSE STRATEGY

The defense strategy, as outlined in the 2014 Quadrennial Defense Review, explains that the nation demands that the Joint Force have the ability to simultaneously protect the homeland; provide a global presence in support of U.S. interests, particularly to assure allies and deter aggression in the Asia-Pacific, European, and Middle East regions; and project power against a range of adversaries and challenges across the spectrum of conflict. The Department's force planning and programming must address both the near-term and long-term priorities derived from these Departmental objectives. To underwrite this ability in the Joint Force, the Department's budget must prioritize capability investments and recovery of the force's readiness while controlling internal cost growth that threatens to erode combat power. It must also develop and maintain a posture of CONUS-based and forward forces that prioritizes deterrence, surge for responsiveness to crises, and the ability to prevail in conflict. Finally, the Department

must prioritize investments in and preparation for emerging 21st century threats, including those related to the space and cyberspace, the nuclear enterprise, and power projection in highly contested environments. This focus means sustaining robust investments in science, technology, research, and development in areas most critical to future conflict, including where there is the greatest potential for game-changing advances. It also requires reforms to headquarters, for structure, health care, and infrastructure so that the needed investment in priorities is possible.

BALANCE THE JOINT FORCE

The Department must balance the Joint Force and adapt to changes in the security environment. The Secretary of Defense has directed the Department to prioritize the challenges presented by ongoing or possible future aggression from China, Russia, Iran, and North Korea, as well as maintaining the capabilities to conduct ongoing counter-terrorism operations. These five challenges are informative to balancing the Joint Force.

Balancing for broad spectrum of conflict. Future conflicts could range from hybrid contingencies against state or non-state actors to high-end conflicts against states armed with weapons of mass destruction and/or advanced anti-access and area-denial capabilities. To address this diverse range of challenges, the U.S. military will continue to invest in a broad range of capabilities to support the full spectrum of possible operations. While preserving hard-won expertise in counterinsurgency and stability operations, the Joint Force must also be prepared to battle sophisticated adversaries employing advanced warfighting capabilities, especially space and cyber. The Department will sustain robust investments in science, technology, research, and development in areas most critical to meeting future challenges or where there is greatest potential for game-changing advances.

Balancing presence and sustaining posture abroad to protect U.S. national security interests. In meeting the defense priorities of the nation, the Department will continue to ensure the right balance is achieved to sustain a global posture that deters aggression and safeguards the nation's allies. The Department will continue its contributions to the Asia-Pacific rebalance, while remaining committed to the security of allies and partners in the Middle East. The Department will continue to work with allies and partners in Europe to promote regional security, Euro-Atlantic integration, enhanced military capability, and enhanced interoperability. Across the globe, DoD will ensure that the Joint Force is properly manned, trained, and equipped in the event of a crisis.

Balancing capability, capacity, and readiness within the Joint Force. The Department's greatest responsibility is to win the nation's wars. The Department will continue to invest in the most capable, ready, and efficient force that can project power globally for full-spectrum operations against a range of threats. The FY 2017 budget request supports this aim in the following ways:

- Sustaining a world-class Army capable of conducting the full range of operations on land, including prompt and sustained land combat, by maintaining a force structure that it can train, equip, and keep ready. The Department will maintain a balance of capability, capacity, and readiness across the Army's total force, including the Active, Guard, and Reserve components. The active component of the Army is reducing its planned post-war end strength from 490,000 to 450,000 personnel by the end of FY 2018. The Army National Guard and the Army Reserve are reducing their planned force structure to 335,000 and 195,000 soldiers, respectively, by the end of FY 2017. The Army continues to move toward stabilizing its total force at 980,000.

Overview – FY 2017 Defense Budget

- Providing stability in Navy shipbuilding while buttressing aviation and weapons to address emerging challenges. The FY 2017 budget request supports the construction funding for 38 ships across the FYDP and supports steady production of destroyers and submarines; ten destroyers and nine submarines are constructed through FY 2021 to support a fleet size of 308 ships. The FYDP shipbuilding construction program includes funding for the Ohio Replacement Program Advanced Procurement beginning in FY 2017; one LHA amphibious assault ship replacement; four T-AO(X) fleet oilers, and continued funding for the refueling and overhaul of the USS GEORGE WASHINGTON (CVN 73). The FY 2017 budget request also funds two littoral combat ships (LCS) and continues to finance the detailed design and construction of the second Ford Class carrier and provides for the procurement of carrier-based aircraft to address a looming strike-fighter shortage in the 2020s, and it bolsters funding for some of the Navy's most capable weapons to provide a powerful deterrent to potential aggressors.
- Resourcing the Marine Corps to be a force-in-readiness, immediately deployable to respond to crises and support contingencies. This budget provides a Marine Corps with a 182,000 active duty end strength, and capable of expeditionary operations across all warfighting functions. The Marine Corps is actively modernizing and preparing for future challenges, as demonstrated by its Joint Strike Fighter program achieving initial operating capability this year, and is increasing this momentum with new technologies to enable its mission set.
- Maintaining an Air Force with global power projection capabilities and modernizing next generation Air Force combat equipment — to include fighters, bombers, and munitions — particularly against increasingly sophisticated air defense systems, while sustaining the health of the combat fleet. To make resources available for these programs and preserve investments in critical capabilities, the Air Force will reduce capacity in some single-role aviation platforms by the end of the FYDP.
- Achieving the right balance and integrated approach to warfighting readiness between the Active Component (AC) and the Reserve Component (RC), which is critical to the Department's overall efforts to size and shape the future Joint Force.

As the Joint Force maintains this critical balance to remain modern, capable, and ready — while reducing end strength — the Department is taking the following steps in the President's Budget submission to develop and protect key capability areas, including:

- Air/Sea: increasing the Joint Force's ability to counter advanced anti-access and area-denial capabilities by continuing to invest in fifth-generation fighters and long-range strike aircraft and munitions, survivable persistent surveillance, resilient architectures, and undersea warfare capabilities;
- Nuclear Deterrence: continuing to invest in modernizing the triad's essential nuclear delivery systems, to include the Ohio Class Submarine, command and control, and, in collaboration with the Department of Energy, nuclear weapons and supporting infrastructure;
- Space: moving toward more resilient systems and system architectures, and pursuing a multi-layered approach to deter attacks on space systems;
- Missile Defense: making targeted investments in defensive interceptors, discrimination capabilities, and sensors;

Overview – FY 2017 Defense Budget

- Cyber: continuing to invest in new and expanded cyber capabilities and forces to operate and defend DoD's networks; enhance DoD's ability to conduct cyberspace operations; support military operations worldwide; and counter cyber-attacks against the United States;
- Precision Strike: procuring advanced air-to-surface weapons that will allow fighters and bombers to engage a wide range of targets, and a long-range anti-ship cruise missile that will improve the ability of U.S. aircraft to engage surface combatants in defended airspace;
- Intelligence, Surveillance, and Reconnaissance (ISR): continuing to invest in systems that are effective in highly contested environments, while sustaining capabilities appropriate for more permissive environments, in order to support global situational awareness, counter-terrorism operations, and other Combatant Command needs; and,
- Counter-Terror and Special Operations: improving the nation's ability to counter terrorist activity by maintaining current SOF end-strength and improving the efficacy of counter-terrorism operations. This requires the Department to budget and plan to sustain persistent, networked, distributed operations to defeat trans-regional terrorist networks, counter other emerging transnational threats, counter weapons of mass destruction, build the capacity of U.S. partners, and support conventional operations.

The Department also recognizes that the size of the force or the level of funding and investments alone cannot entirely reduce the risks the nation faces. The Department must also continue to evolve its thinking on its warfighting concepts and planning, toward developing a more diverse, adaptive, and less costly playbook of options for how the Joint Force should operate in the emerging security environment.

In addition to balancing Joint Force capability, capacity, and readiness, this budget supports the Department's continued efforts to rebalance internally, to prioritize resourcing for warfighting. This includes reducing the Department's major headquarters' operating budgets across the Department and reducing major headquarters staff by 25 percent in the Office of the Secretary of Defense and the Defense Agencies.

The DoD will remain committed to increasing productivity in defense acquisition. The Better Buying Power initiative seeks to achieve affordable programs by incentivizing productivity and innovation in industry and government, eliminating unproductive processes and bureaucracy, promoting effective competition, improving tradecraft in contracted acquisition of services, and improving the professionalism of the total acquisition workforce.

The Department can be better stewards of taxpayer dollars by eliminating excess infrastructure; it already has more infrastructure than needed, and the excess will increase as DoD reduces its end strength. The best way to eliminate unneeded infrastructure is through the Base Realignment and Closure (BRAC) process. Once again, Congress has denied the Department's request for a BRAC this year. Congress should approve the Department's request to authorize another BRAC round in 2019. Currently, each Military Department is expending much needed funds to maintain a surplus of facilities. A new round of BRAC will put about \$2 billion back in the operating forces by 2025.

SUPPORTING PERSONNEL

As this budget request continues efforts to rebalance the Joint Force and the Department, the United States must maintain its sacred contract with its service members: to properly compensate and care for Service members and their families both during and after their service,

Overview – FY 2017 Defense Budget

and to provide U.S. troops the best training and equipment possible so that they can safely accomplish their missions. The Department has expanded opportunities in the military for women, to include opening up previously banned combat roles, working to eliminate sexual assault, and integrating gay and transgender troops to serve openly and equally in the military. The Department must continue to provide the best possible care to those returning from combat.

With increasing personnel costs such as healthcare, the Department cannot afford to sustain the rate of growth in military compensation experienced over the last decade. The Department and the American people have been rightfully supportive of the men and women in uniform over more than a decade of war, providing increases in military pay and benefits as they endured the increased combat operational tempo. These changes have significantly closed compensation gaps with the private sector and have appropriately recognized the sacrifices of those who are serving and have served, and their families. The Department is proposing changes that will ensure it can continue to offer a competitive compensation package to recruit and retain the Joint Force of the future.

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3. MANAGING ENDURING READINESS CHALLENGES

INTRODUCTION

Key Initiatives
• Generating Service Capabilities • Generating Joint Capabilities

The Fiscal Year (FY) 2017 budget request reflects the Secretary's vision for a defense program that effectively rebalances today's persistent operational demand with current and future readiness for full-spectrum warfare within the funding caps established by the Bipartisan Budget Act (BBA) of 2015 for National Defense. The requested funding levels will allow the Joint Force to meet steady state demand requirements and strategic obligations, and support the Military Departments' ongoing readiness recovery plans. At \$14 billion above the Budget Control Act (BCA) of 2011 sequestration level funding caps, the FY 2017 topline affords the Department the opportunity to protect investments and priorities critical to securing national objectives at home and abroad.

The refocus to full-spectrum readiness recovery that began in FY 2014 revealed the severity of the Department's readiness deficiencies after 14 years of counterinsurgency-centric campaigns in Iraq and Afghanistan. The Military Departments and combatant commands have oriented their pipeline metrics to a full-spectrum readiness recovery model to inform resourcing and sourcing decisions that will improve readiness throughout the force. Funding shortfalls due to sequestration in FY 2013 seriously disrupted the process and delayed targeted recovery dates. Since then, the return of increased and predictable funding levels has put the Department on the right course to address its competing challenges.

The Military Departments remain dedicated to meeting the complexity and pace of today's operational demand while concurrently rebuilding core readiness. The funding request for FY 2017 supports their efforts and allows the Department to take intended risk in balancing today's requirements and countering tomorrow's threats. The Military Departments tackled their most direct readiness concerns with restored readiness funding under the Bipartisan Budget Agreement (BBA) of 2013 and accelerate those efforts with the funding requested for FY 2017.

Each Military Department will focus on its top priority readiness effort. The Army will optimize Combat Training Center (CTC) throughput capacity to provide Brigade Combat Teams (BCTs) with increased opportunities for full-spectrum training. The Navy will continue implementation of its Optimized Fleet Response Plan (OFRP), which balances the preservation of critical maintenance and training while maximizing employability of naval forces. Carrier Strike Groups (CSGs) and Amphibious Readiness Groups (ARGs) are being phased into the plan with the final group entering in FY 2018. The Marine Corps fully funded the Integrated Combined Arms Exercises for all elements of the Marine Air Ground Task Forces to recover full-spectrum readiness and maintain its role as the nation's crisis response force. The Air Force will optimize funding for flying hours and invest in exercise capacity and training range modernization to maximize home station training opportunities; all 13 fighter squadrons that stood down under sequestration can now fully execute their flying hours. For the U.S. Special Operations Command (USSOCOM), there will be an increased focus on language and cultural expertise training and continued enhancement of Special Operations Forces (SOF) support to the Geographic Combatant Commands.

The FY 2017 budget request balances support for current operations with a still-emerging readiness recovery. Although the Military Departments made significant progress in the last 2 years under the BBA of 2013, there are limits to what funding alone can do to recover their full-spectrum readiness. The Military Departments require a combination of resources, a stable

Overview – FY 2017 Defense Budget

readiness funding profile, and time to rebuild full-spectrum readiness across the Future Years Defense Program (FYDP).

Fiscal stability is required for the Military Departments to efficiently program a balanced approach to longer-term institutional readiness and health, and each Service has a unique plan designed to meet readiness recovery objectives just outside the FYDP. The FY 2017 funding levels will advance these plans — just slower than planned before the BBA of 2015 funding caps — with their respective focus areas of:

- The Army's Decisive Action (DA) CTC rotations, supported with home station training, serving as the primary mechanism to build full-spectrum readiness;
- The Navy's OFRP cycle induction as it attempts to clear away its long-term maintenance back-log;
- The Marine Corps' focus on leader-to-lead ratios while maintaining its crisis response capabilities; and
- The Air Force's rebuild of high-end readiness at home station with a reduced Deploy-to-Dwell ratio.

Time is a critical element that funding alone cannot create, and rebuilding readiness is just as much of a function of time as it is of resources and fiscal stability. Examples include:

- Opportunities for major exercises and combined training;
- Creating seasoned shipyard artisans, professional Non-Commissioned Officer development, and leader-to-led ratios; and
- Stable maintenance cycles.

The Department faces increasing operational pressures that further exacerbate issues caused by undesirable sequestration level funding. Unrelenting combatant commander requirements are disrupting manning, training, and equipping cycles. Although the Military Departments remain hard pressed to sustain high levels of operational demands worldwide while concurrently rebuilding core readiness for high-end contingency operations, the FY 2017 budget request allows the Department to take calculated risk in balancing today's requirements and those to counter 21st century threats.

The readiness recovery and careful strategic tradeoffs requested will be lost if the Department returns to the sequestration funding levels in FY 2018 and beyond. The Military Departments are able to achieve their readiness recovery goals under the President's topline, but on a longer timeline than previously expected. A return to the sequestration level caps would undermine these near-term advancements and render Military Departments' readiness recovery goals unachievable.

The following sections discuss FY 2017 force generation and resourcing strategies for the Military Departments, the United States Special Operations Command (USSOCOM), and the United States Transportation Command (USTRANSCOM). These readiness investments are needed to improve full-spectrum readiness recovery and capability.

GENERATING SERVICE CAPABILITIES

The Military Departments organize, train, and equip units to meet operational requirements. In doing so, each Military Department creates a force generation process that combines the basic inputs of labor and capital to provide the requisite supply of ready forces. These force

Overview – FY 2017 Defense Budget

generation processes naturally differ based on the particulars of the capabilities being produced and the demand signal derived from current operations and strategic guidance.

Army

While the Army continues to provide ready forces for known and emergent Combatant Command requirements, the rebuilding of Army core readiness has plateaued. Increasing emergent demand strains Army capacity even while budgetary constraints cause downsizing, which challenges the rebuilding of readiness. At current readiness levels, the Army assumes risk in its ability to meet the most critical requirements of the National Military Strategy (NMS) by using resources simultaneously needed for the Joint Force to achieve national security objectives elsewhere in the world.

Generating Army Readiness

To decrease stress on high demand capabilities, the Army will preserve and build unit readiness while effectively adapting to emergent demand through innovative sourcing solutions. Additionally, the Army will implement several initiatives including administrative and medical deployability personnel policy revisions, improved standardization to unit training assessment procedures, and, by FY 2017, an updated force generation process to achieve higher unit readiness levels over longer periods of time.

Readiness Management under PB 2017

The Army's readiness recovery goal is to source current operations with ready forces while ensuring sufficient forces are ready to achieve combatant command contingency requirements in accordance with the NMS. Achievement is heavily influenced by four factors: demand for Army forces; required end strength drawdown and force reorganization efforts; time required to regain decisive action (fighting major combat operations against near-peer adversaries) proficiency; and fiscal uncertainty and budgetary constraints. The reductions required to comply with the BBA of 2015 and the FY 2017 budget request will increase risk in achieving previously established readiness recovery goals.

The BBA of 2015 provides a measure of much needed near-term certainty to the Army's FY 2016 and FY 2017 budgets and mitigates some of the funding reductions under the sequestration level caps, but it does not reverse the effects and the backlog caused by reductions that will most likely affect near-term readiness (operations) and future readiness (modernization). The revised FY 2017 program decreases collective operational training proficiency across Army ground formations, dramatically limits modernization of the UH-60 Blackhawk and CH-47 Chinook helicopter fleets, and reduces funding across facilities sustainment, modernization, and construction programs from already historically low levels.

Training

The Army will prioritize FY 2017 deploying Regionally Aligned Force (RAF) and CTC rotational units to ensure the Army meets combatant command requirements. However, additional reductions below the BBA of 2015 caps in FY 2017 training readiness would come at the expense of non-deploying units, which could be funded at reduced collective training proficiency levels. Additionally, there would be cuts to critical Training Support Systems and reductions to institutional training seats, including: Reserve Component (RC) military occupational specialty qualification seats, civilian education, and functional training. All of this will prevent achievement of training proficiency and readiness sought under the requested funding levels.

Overview – FY 2017 Defense Budget

Figure 3-1. Required, Planned, and Executed Rotations through Maneuver Combat Training Centers (Unified Land Operations (ULO) versus Mission Rehearsal Exercises – MRE)

	FY 2015	FY 2016	FY 2017	FY 2018-2022
CTC Capacity	21 Rotations	21 Rotations	21 Rotations	21 Rotations
Planned CTC Rotations	16 x DA/ULO 1 Hybrid MRE/DA 2 DA Enabler	16 x DA/ULO 2 Hybrid MRE/DA 1 DA Enabler	16 x DA/ULO 3 Hybrid MRE/DA	21 x DA/ULO
Executed CTC Rotations (DA/ULO vs MRE)	15 x DA/ULO 2 Hybrid MRE/DA 2 DA Enabler		<i>DA/ULO: Decisive Action in support of Unified Land Operations</i> <i>MRE: Mission Rehearsal Exercise</i>	

Equipping

With the FY 2017 funding request (consistent with the BBA of 2015) established to achieve a force of 980,000 by FY 2018, the Army accepts the greatest risk in future readiness in the form of equipment modernization reductions. To absorb modernization funding reductions or adjustments, the Army will delay the fielding of a number of UH-60 Blackhawk helicopters and operate at a minimum sustaining rate for procurement of Apaches, Blackhawks, and Chinooks. Additionally, the Army will reduce the modernization of vehicles intended for Infantry Brigade Combat Teams (IBCTs) and other missions while also reducing mission command equipment modernization, causing delays to some IBCT command post upgrades. The Army's priority is to equip Soldiers involved in current operations today, while accepting mid-term risk to modernize for the future.

Sustainment

With FY 2017 reductions to sustainment readiness, the Army anticipates decreased equipment readiness rates, potentially affecting improvement to force readiness levels. There will be impacts to corrosion assistance to aviation and missile programs and significant reductions to Army depot production, affecting aviation, communications electronics, and a variety of other fire and mobility assets. Additionally, with the elimination of labor hours across five depots, there are risks to maintaining critical skills needed to meet Title 10 core capability requirements.

Installations

To resource crisis response demands and existing combatant command requirements, the Army has taken risk in installation sustainment funding. It is worth noting that major training facilities like the CTCs, which provide the pinnacle of Army unit training and are a vital part of Army readiness, draw on these same installation funding lines. While the Army accepts short-term risk in modernizing and sustaining its installations, these strategic tradeoffs have long-term consequences that eventually degrade future readiness and capabilities.

Because the funding levels in the BBA of 2015 do not keep pace with the reality of the strategic environment, the Army's readiness recovery goal is at risk. At the projected funding levels and with increased requirements, the Army will be unable to improve readiness and make critical investments in capabilities and infrastructure. Additionally, a return to sequestration level funding limits in FY 2018 would further delay the Army's goal for regaining decisive action proficiency.

Navy

Generating Navy Forces

Overall Navy readiness continues to improve under its OFRP, which began phased implementation in FY 2015. A key readiness benefit of OFRP is to preserve critical maintenance and training while maximizing employability of Navy forces. This provides stable and predictable maintenance and modernization plans, as well as forces trained to a single full-mission readiness standard. The OFRP combines several phases of the integrated training period in a logical manner that meets all of the previous requirements in fewer days. It similarly combines inspection requirements within specified periods to enhance their contribution to force generation rather than delaying it. The improved focus on predictably building readiness will also improve quality-of-work and quality-of-life for Navy Sailors. Additional benefits include fixed Carrier Strike Group (CSG) and Amphibious Readiness Groups (ARGs) composition with continuity of command and alignment of manning through the cycle.

Figure 3-2. Programmed Navy Training Throughput (assumes continued base budget and OCO funding levels reflected in the FYDP supporting the FY 2017 budget request for steaming days and maintenance activity in support of named operations)

	FY 2016		FY 2017		FY 2018	
	BASIC	INT*	BASIC	INT	BASIC	INT
Carriers	4	3	5	3	4	3
Carrier Air Wings	4	3	4	3	4	3
CG/DDG/ LCS	40	23	44	25	45	26
LHA/LHD/LPD/LSD	15	11	14	9	16	12
SSNs	13	32	19	3	17	28

*INT = Integrated, refers to aggregated training of all units in a Carrier Strike Group/Amphibious Ready Group (e.g. Airwing training at Naval Air Station Fallon, NV; COMPTUEX (Composite Training Unit Exercise); JTFEX (Joint Force Training Exercise))

To date, Navy has inducted all Maritime Patrol and Reconnaissance Squadrons (P3 Orion/P8 Poseidon), Naval Expeditionary Combat Command forces, and attack submarines (SSNs), as well as guided missile submarines (SSGNs), into the OFRP. Because of the number of ships involved, CSGs and ARGs are being phased into the plan. There are currently three CSGs and four ARGs inducted into the OFRP. The final group of CSGs and ARGs will enter the OFRP in FY 2018.

Operation and Maintenance

Ships: The FY 2017 funding request supports the continued implementation of the OFRP. As one part of that process, there is a continued focus on level-loading carrier maintenance over three OFRP cycles to deliver a more consistent output. With the funding levels reflected in the FY 2017 budget request FYDP, the OFRP is on track to produce an overall increase in aircraft carrier (CVN) employability across the FYDP and achieve its goal of an average of 2 deployed and 3 surge ready CSGs by the end of FY 2021. The Navy anticipates a temporary dip in FY 2020 in CVN surge capacity because the USS GEORGE WASHINGTON and USS JOHN C STENNIS Refueling Complex Overhauls overlap.

With Overseas Contingency Operations (OCO) funding, the FY 2017 budget request funds ship operations to the anticipated level of required steaming days (58/24 operating tempo) but less than the anticipated need for Operating Target (OPTAR) funding (89 percent). If OPTAR funding remains at this reduced amount over a period of time, it is likely that material and training readiness will be impacted. The FY 2017 budget request fully protects ship

Overview – FY 2017 Defense Budget

maintenance, including surface ship and aircraft carrier maintenance reset. The material condition reset of Navy capital assets will require continuing investment through the FYDP. Together with protecting the time to train and maintain, this material condition reset is also essential to the long term readiness of the force.

Aviation: The intent of FY 2017 Flying Hour Program funding is to deliver a Carrier Air Wing presence as directed by the Global Force Management Allocation Plan. These deployed presence levels will be attainable at the expense of non-deployed units, due to the effects of F/A-18 A-D Legacy Hornet Out-of-Reporting caused by aviation depot throughput challenges and the Ready Basic Aircraft gap caused by flight line maintenance issues. All units will continue to execute the Fleet Readiness Training Plan and be ready to deploy; however, sustainment levels will be affected by these issues. To recover, Navy realigned funding into engineering and program-related logistics, providing increased engineering support in the aviation depots and flight line assessments of aircraft to speed the repair process. The FY 2017 funding request sustains funding in aviation support and enabler accounts directed at reducing depot work in process. Similar to shipyard hiring actions, Navy has also stepped up hiring in its Aviation Depots. The FY 2017 funding request funds Aviation Depot Maintenance inductions to an executable level given the current level of work in process. The Navy also plans to reduce the number of carrier air wings from ten to nine, which will support its OFRP goals.

Manpower/Personnel

Manning units with the right number and type of properly trained, properly experienced Sailors is a critical element of readiness. To ensure continuing readiness, Navy tracks how many billets are filled, and whether they are filled by individuals with the requisite qualifications. These data sets are closely managed by the Fleets, each warfare community, and by individual units to predict future readiness and correct critical shortfalls for deploying units.

Installations

The Navy continues to take calculated risk in funding installations but is mitigating this risk by focusing investment on capabilities that directly support the operational forces, implementing a force laydown that supports the defense strategy, and arresting degradation of facilities by focusing on the “envelopes” (roof, walls, support structures) of our buildings. As the Navy funds installation operations, it continues to prioritize fleet operations, quality-of-life programs, base security, and public safety while taking increased risk across other base support programs. This budget request provides infrastructure to support combatant commanders, enable initial operational capability for new platforms and missions, upgrades energy and utility systems, and recapitalizes naval shipyards. The Navy maintains a commitment to meeting the key needs of service members and their families.

Marine Corps

The Marine Corps is committed to remaining the nation's premier expeditionary force-in-readiness, capable of responding to crises anywhere around the globe at a moment's notice. Marines are forward deployed, protecting the nation's security by conducting operations to defeat and deter adversaries, support partners, and create decision space for national-level leaders. Even with the reduced BBA of 2015 funding levels, the FY 2017 budget request continues to support that role.

The Marine Corps prioritized funding for end strength, training, and operational accounts to support a high level of near-term operational needs. The FY 2017 budget request will continue to resource the Marine Corps to accomplish the same guidance and objectives as in the FY 2016 budget. The Marine Corps will emphasize near-term readiness for deployed and next-to-deploy forces while maintaining top modernization programs including the Amphibious

Overview – FY 2017 Defense Budget

Combat vehicle, the Joint Light Tactical Vehicle, the Joint Strike Fighter, and the CH-53K Heavy Lift Helicopter. The FY 2017 budget request funds an 182,000 active component end strength, which supports a 1:2 deploy-to-dwell ratio for major force elements. Infrastructure sustainment, equipment modernization and military construction will continue to be the “bill payers” for crisis response capability. These tradeoffs have long-term consequences that will eventually degrade future readiness and capabilities, especially with the sequestration level funding caps.

The Marine Corps continues to manage readiness across five pillars: (1) Capability and Capacity to Meet Requirements; (2) Unit Readiness; (3) High Quality People; (4) Infrastructure Sustainment; and (5) Equipment Modernization. Maintaining balance across these pillars is the key to achieving and sustaining the level of readiness expected of the Marine Corps. This budget reflects hard choices that the Marines made to protect readiness largely at the cost of modernization. The following paragraphs describe the Marine Corps’ approach for generating ready forces today and informing an investment strategy that will ensure the future readiness of the Marine Corps.

Generating Marine Corps Readiness through Capability and Capacity

Specific Corps-provided capabilities will be sourced from standing units and newly assembled task organized units. Such units include Special Purpose Marine Air Ground Task Force (SPMAGTF)-Africa and the Black Sea Rotational Force, both of which have been permanently operating in the African and European areas. A second SPMAGTF-Crisis Response-Central Command expands the Commander, U.S. Central Command’s operational reach and a third SPMAGTF-U.S. Southern Command will intermittently operate in Central America. These units assist combatant commanders in executing theater security cooperation plans by providing military-to-military engagement such as bi/multilateral training, thereby building partner confidence and deterring would-be adversaries. Moreover, these Marine units are capable of rapid crisis response to seize the initiative and defeat those who threaten U.S. interests. While the SPMAGTF concept has proven its utility in today’s environment, inherent challenges, such as overflight authorities and freedom of movement, make traditional amphibious Marine Expeditionary Units (MEUs) the preferred crisis response formation to meet combatant commander requirements. This increased forward presence is captured in the force posture plan, a global distribution of Marine Corps’ capabilities that meets the most critical global force management demands. Even with the reduced funding, the FY 2017 budget request is designed to achieve the tenets of the force posture plan.

The rebalance to the Pacific also remains a top priority and is reflected in the resourcing of the Unit Deployment Program (UDP) as well as Pacific-based operational units and MEUs. The establishment of a rotational presence of Marines in Darwin, Australia, positively impacts U.S. allies’ confidence in the Corps’ ability to respond to crises in the South and Southeast Asian littorals. Collectively, the Marine Corps’ forward postured forces provide scalable, expeditionary units that are capable of functioning as the lead elements of a crisis response force. Additionally, the reestablishment of three permanent Marine Expeditionary Brigade (MEB) command elements provides additional operational capability that is light enough for rapid employment, heavy enough to prevail against threats in the littorals, and can command and control operations up to the Marine Expeditionary Force level. The MEB is capable of joint forcible entry operations and could deploy as the nucleus of a Joint Task Force Headquarters. Regionally aligned SPMAGTFs, forward deployed and forward stationed units (i.e., MEU and UDP), and MEBs provide expeditionary crisis response capability for the nation. The FY 2017 budget request enables the Marine Corps to sustain these capabilities in the near-term.

Overview – FY 2017 Defense Budget

Unit Readiness

The Marine Corps provides well trained, highly ready forces to meet the combatant commanders' requirements. The Marine operating forces depend on funding for training and maintenance of equipment to preserve and enhance their readiness. Although deployed Marine forces are at the highest levels of readiness, this readiness cost often comes at the expense of non-deployed units that frequently provide equipment and personnel in support of deploying units. The FY 2017 budget request helps address some of the most acute readiness challenges for non-deployed forces.

Equipment reset: Reset is comprised of the actions taken to restore units to a desired level of combat capability commensurate with future missions. While the FY 2017 budget request adequately resources units throughout the training and deployment cycle and funds ground depot maintenance to 69 percent of the validated requirement, the readiness of non-deployed units will begin to degrade in the future.

Aviation depot maintenance is equally critical to maintaining readiness. The Marine Corps has registered its concern about the impact that aging platforms, high demand/use, and constrained depot funding is having on aircraft availability and squadron readiness. The FY 2017 budget request provides some much-needed funding into the aviation depot programs.

Training: The FY 2017 budget request maintains a focus on operational readiness and service-level training. It funds crisis response capabilities in support of the combatant commands. However, core capabilities such as amphibious training are strained by the lack of resources, amphibious ships, and the time needed to reset equipment and train to full-spectrum capability.

The FY 2017 budget request continues to support the Marine Corps' service-level training program by fully funding an Integrated Training Exercise (ITX) program designed to recover full-spectrum readiness. During FY 2017, the ITX is funded to provide training for up to 10 infantry battalions, 5 artillery battalions, 5 logistics battalions, 30 flying squadrons, and additional aviation support elements. Figure 1 displays the Marine Corps' service training exercise plan.

Figure 1. Planned Large Training Exercises

Marine Corps	Annual Training Exercises for 2017	
	Integrated Training Exercises	Mountain Exercise
Infantry Battalion	10	2
Infantry Regiment	0	0
Artillery Battalion	4.5	0
Logistics Battalion	5	0
Squadrons	30	0

Figures represent maximum number of service level funded exercises depending upon global environment

High Quality People

Recruiting and retaining high quality people plays a key role in maintaining the Marine Corps' high state of readiness, as such individuals produce higher performance, reduced attrition, increased retention, and improved readiness for the operating forces. The FY 2017 budget request supports an 182,000 active duty and 38,500 reserve end strength. Additionally, FY 2017 budget request supports a 1:2 deploy-to-dwell ratio for active duty forces and 1:4 for reserves, using limited and targeted total force solutions. This postures the Marine Corps to preserve forward presence and crisis response capabilities and creates options and decision space for the nation's leaders by taking acceptable risk in major combat operations and large, long-term stability operations.

Overview – FY 2017 Defense Budget

Infrastructure Sustainment

Sustainable readiness is inextricably linked to the availability and condition of real property and infrastructure. Adequately resourcing the sustainment of Marine Corps bases and stations is essential to safeguarding unit readiness, as bases and stations provide the means by which units conduct training and deploy.

The FY 2017 budget request allows the Marine Corps to maintain DoD facility maintenance standards, but will require deferment of new construction and restoration projects in the near-term. The FY 2017 budget request funds facility sustainment to 70 percent of the Department's facility sustainment model. The Marine Corps will continue to optimize base operations support and leverage improved training infrastructure to ensure the readiness of its expeditionary forces.

Equipment Modernization

The Marine Corps' ground and aviation equipment must meet the needs of current and emerging security environments. As the Marine Corps maintains its priority on current readiness, it has had to make difficult choices about modernizing and upgrading equipment. The FY 2017 President's budget allows the Marine Corps to focus funding on its top priority programs while accepting risk with legacy platforms.

The Marine Corps is fully committed to funding and maintaining its top modernization programs including the Amphibious Combat Vehicle, the Joint Light Tactical Vehicle, the Joint Strike Fighter, and the CH-53K Heavy Lift Helicopter. However, the FY 2017 budget request continues to accept risk in both equipment sustainment and service life extensions that sustain legacy equipment.

Air Force

Regaining full-spectrum readiness remains a top priority for the Air Force, but the Air Force continues to have significant readiness concerns. The too-narrow focus on assigned operational missions over the last 14 years eroded full-spectrum readiness across the Combat Air Forces (CAF). Readiness remains at historically low levels following a readiness decline in FY 2015. The Air Force is forced to make tough budgeting decisions that limit readiness improvement shortfalls to meet the demands of full-spectrum operational readiness required by the current strategy. Under the FY 2017 budget request, the Air Force weighed the balance between strategy-based modernization and acquisition programs, and the need to repair readiness shortfalls.

To fully support the requirements of the current defense strategy, Air Force operational elements must be postured to respond rapidly anywhere on the globe. The Air Force remains committed to building and maintaining a high level of readiness across the total force at all times, while continuing to modernize and acquire the capabilities of that force in relation to potential adversaries. Air Force recapitalization and modernization efforts (i.e., KC-46 Pegasus, F-35 Joint Strike Fighter, Long Range Strike Bomber (LRS-B), HC-130J Combat King, HH-60W Combat Rescue Helicopter) will improve both capability and capacity in the long-term, but will impinge on short-term readiness as units transition to these new weapons systems. Moreover, the continued pressure of deployments and a chronic shortage of Airmen in critical skill positions are limiting recovery efforts.

Assigned mission readiness, particularly for the CAF, currently meets the combatant commanders' rotational demand. However, it leaves few full-spectrum ready forces available to handle unforeseen surge or contingency requirements. In order to meet the Air Force's

Overview – FY 2017 Defense Budget

80 percent full-spectrum readiness goal, the CAF needs to return to and sustain a 1:4 deploy-to-dwell ratio.

Enduring global operations and emerging contingencies continue to impede the at-home training opportunities needed to regain the full-spectrum readiness levels required by the Quadrennial Defense Review (QDR) strategy. These operational demands are unlikely to decrease in the near term. Going forward, balancing rotational requirements with the full-spectrum training required to meet the QDR will remain a significant element of Air Force strategy.

Generating Air Force Readiness

The Air Force relies on its proven “5-Levers of Readiness Model” to inform its readiness budgeting in the FY 2017 budget request. These levers are: (1) Flying Hour Program (FHP), which includes the dollars associated with sortie production; (2) Weapons System Sustainment (WSS), which includes dollars associated with aircraft availability production or enabler war-fighting systems; (3) Training Resources Availability, which encompasses ranges, live/virtual construct, and dollars to provide capabilities to replicate realistic training; (4) Critical Skills Availability (CSA), which includes specialty level enlisted training, special certifications and other skills that aid in producing aircraft availability or qualified enablers; and (5) Deploy-to-dwell, which is affected by force capacity against current tasking. Each of these inter-dependent variables works to produce full-spectrum ready forces. Because they are interrelated, funding one of these levers, without appropriately funding the others, will not produce the desired full-spectrum readiness outcomes.

With the limited BBA of 2015 funding cap, the FY 2017 budget request addresses all five levers in a balanced fashion; it has slightly improved some key end-of-FYDP readiness building areas like critical skills accessions (end strength) and resources for training and ranges, assuming the sequestration level caps are increased to the FY 2017 FYDP levels. These investments will help the Air Force build the capacity to execute a readiness building training program later in the FYDP. In the short-term, the Air Force capped training flying hours and weapon system sustainment accounts to executable levels and is monitoring Global Force Management reforms that limit commitments on highly stressed force elements.

Current expectations pertaining to the recovery of full-spectrum readiness are that today’s levels will persist from FY 2016 through FY 2019. With the investments being made in long-lead items (i.e., maintenance manpower, training resources and weapons system sustainment) associated with sustained improvements in deploy-to-dwell and predictable resource levels, the Air Force expects to see a gradual but steady climb in readiness beginning in FY 2020, assuming the funding levels in the FY 2017 FYDP are provided. The Air Force will achieve its 80 percent full-spectrum readiness goal 8 to 10 years after these conditions are set.

Manpower/Personnel

Currently, the Air Force is facing a shortage of skilled maintenance personnel, specifically in the most experienced categories. The FY 2017 budget request funds maintenance manning shortfalls in the F-16 Fighting Falcon, F-15E Strike Eagle, HH-60 Combat Rescue Helicopter, and B-1 Lancer (1,057 positions). The development of skilled maintainers is a 5- to 7-year process, which will be complicated by F-35 Joint Strike Fighter and KC-46 Pegasus transitions. The investment in human capital now will help the Air Force build the appropriate skill level mix to execute an optimum training program later in the FYDP.

Overview – FY 2017 Defense Budget

Training and Equipment Maintenance

The Air Force's Flying Hour Program (FHP), Weapons System Sustainment (WSS), and Training Resource Availability (TRA) are inextricably linked. For example, funding flying hours without associated WSS will cause hours to be flown at a pace where WSS no longer supports aircraft availability and prevents execution of additional the flying hours. The FY 2017 budget requests FHP funds at the executable level limited by combat deployments and sortie generation rates. These FY 2017 FHP funds will help the Air Force to hold onto readiness gains. To sustain the requested levels of flying, WSS is funded at 88 percent of the enterprise level using FY 2017 base and OCO funding requests.

The FY 2017 budget request increases the TRA funding to \$1.27 billion to support the full-spectrum training needed to generate operational readiness. The FY 2017 budget request funds upgrades to critical items needed to replicate realistic threat environments, thereby improving training integration for 4th and 5th generation aircraft. Additionally, the budget request supports increased operational availability for upper tier training support, such as RED FLAG, GREEN FLAG, Adversary Air, other instrumented ranges, and includes Operational Training Infrastructure investments for the Live, Virtual, and Constructive (LVC) enterprise (see Figure 2 below).

Figure 2. Air Force Historical and Planned Large Force Exercises

	FY 2015 Executed	FY 2016 Planned	FY2017 Planned
RED FLAG Nellis	4	4	4
RED FLAG Alaska	3	3	3
GREEN FLAG West	9	9	9
GREEN FLAG East	9	9	9

United States Special Operations Command

The USSOCOM's FY 2017 budget request focuses on delivering innovative, low-cost, small footprint solutions to the geographic combatant commanders (GCCs) to help achieve the nation's current and future security objectives. The USSOCOM will continue to use joint exercises, rotational and permanent forward presence, and robust military advisory capabilities to be a more efficient security partner with nations and organizations around the globe, sharing USSOCOM's vision of freedom, stability and prosperity. The FY 2017 baseline and OCO budget requests achieve these objectives by maintaining readiness, balancing risk, and increasing Research, Development Test and Evaluation (RDT&E).

The USSOCOM's readiness status remains stable across the enterprise. However, USSOCOM is beginning to see minor impacts to the forces' ability to accomplish missions and support the GCCs. The Special Operations Forces (SOF) would begin to lose its technological superiority or be forced to jeopardize various essential recapitalization and modernization programs leaving the force with reduced capability and/ or capacity in critical areas if the sequestration level funding caps are provided in FY 2018 and beyond.

One of USSOCOM's greatest concerns is the potential impact of fiscal reductions to the Military Departments' readiness, which directly affects SOF. The USSOCOM has already witnessed reductions to the Military Departments that negatively affect SOF in a variety of ways. The Naval Special Warfare Command is seeing training challenges associated with lower fleet asset availability, which impacts readiness and interoperability. The Marine Forces Special Operations Command is experiencing reductions in access to some important school seats. The U.S. Army Special Operations Command is seeing a reduction in the military training

Overview – FY 2017 Defense Budget

specific allotment as well as reduced staffing at heavily used ranges. If further Military Department program reductions become necessary, SOF is likely to see more negative impacts to its capabilities.

Enhancing Capabilities for Full-Spectrum Readiness

The USSOCOM continues to provide properly trained, equipped, and culturally-aligned SOF to the GCCs. By continually building and maintaining relationships with interagency and international partners across the Areas of Responsibility, USSOCOM provides capabilities critical to achieving national security objectives and address emerging crises. To provide the GCCs with these types of unique capabilities, USSOCOM must invest in the types of programs and projects that keep SOF at a high state of readiness.

To maintain readiness, the FY 2017 budget request continues to support deployment for Phase Zero Operations and maintains sufficient surge capacity to support Operational Plans and contingencies. The USSOCOM's keys to being ready to support these ongoing and future operations and contingencies require enhancing the capabilities of USSOCOM's individual SOF operators, maintaining a robust fleet of air, ground, and maritime platforms uniquely tailored to support SOF's unique core activities, and enhancing USSOCOM's overall intelligence, surveillance, and reconnaissance capabilities. As a result, much of USSOCOM's procurement of SOF-Peculiar modifications is tied to Service-managed capabilities and platforms as the foundation of USSOCOM's core activities. The Major Force Program-11 buying power is highly dependent on Military Departments' continued investment in these baseline capabilities and platforms.

Military Construction

The USSOCOM's military construction (MILCON) addresses SOF operations, maintenance, training, and storage facility requirements at 22 locations in the continental United States and 5 overseas locations across the FYDP. The FY 2017 budget request funds 16 projects supporting programmed force structure, recapitalization, capabilities, and missions. It supports the basing of CV-22 Ospreys at Yokota Air Base, Japan, and MC-130J Commando IIs at Kadena Air Base, Japan.

Training and Engagements

The USSOCOM continues to focus on cultivating its premier global training venue, the Joint/Combined Exchange Training (JCET), which allows a light footprint SOF detachment to closely partner with host nation countries. The FY 2017 budget request includes additional JCETs funding to support intra-theater airlift during exercises.

Capability Renew, Realignment, and Modernization

The USSOCOM added funding to the MH-47G Combat Mission Simulators Renew program to align USSOCOM funding with the U.S. Army buy rate of eight aircraft per year. This ensures the optimum production schedule and timeliness of delivery to preclude sustainment, safety, and obsolescence from impacting the SOF heavy lift helicopter fleet.

The U.S. Air Force adjustments to the C-130 Hercules recapitalization schedules drove USSOCOM's changes to the procurement and installation schedules for SOF modifications. These adjustments allowed realignment of resources such as the AC-130J Ghost Rider precision strike package (PSP) and MC-130J Commando II aircraft modifications. During the development phase of the previous terrain following/terrain avoidance (TF/TA) radar program of record, USSOCOM identified significant concerns with the radar performance and its ability to meet defined user requirements. After conducting a comprehensive programmatic assessment, USSOCOM decided to revise its acquisition strategy for the AN/APQ-187 Silent Knight Radar

Overview – FY 2017 Defense Budget

(SKR) development in order to field TF/TA radar with associated controls and displays to fulfill SOF requirements for the MC-130J aircraft.

RDT&E

Innovative new technologies are necessary to maintain SOF superiority against emerging threats. The USSOCOM continually researches, develops, and acquires new technology to provide the GCCs and future SOF operators with cutting edge technology and capabilities capable of defeating emerging threats.

The USSOCOM aligns resources and capabilities to position USSOCOM to maintain a ready and capable force. The changes reflected in the FY 2017 budget request and to the supporting FYDP provide greater balance between capability, capacity, and readiness, and will enhance SOF support to the GCCs and enable USSOCOM to meet the challenges of the future.

GENERATING JOINT CAPABILITIES

The FY 2017 budget request reflects investments in joint readiness. The operational readiness of units includes proficiency in Military Department-specific tasks as well as the integration of those tasks as part of a cohesive Joint Force. The overall mission success highly depends on the ability of the Military Departments to operate seamlessly with one another as well as with interagency organizations and our international partners.

United States Transportation Command

The FY 2017 budget request provides adequate resources for U.S. Transportation Command (USTRANSCOM) to fulfill its mission. Cyber threats and Anti Access/Area Denial will become an ever expanding threat to USTRANSCOM's ability to deploy and employ military forces over trans-oceanic distances in support of U.S. national interests. These challenges will continue to be a top priority in USTRANSCOM's future plans.

The Transportation Working Capital Fund (TWCF) allows USTRANSCOM, through both organic and commercial means, to provide reliable distribution and mobility operations to the Military Departments and combatant commands while preserving the readiness of its forces. The TWCF provides USTRANSCOM with the opportunity to sustain organic readiness and guarantees that commercial providers can maintain healthy levels of readiness and capacity. Declining transportation workload that results from reductions in Afghanistan will challenge the ability to sustain commercial surge capacity. This increases risk in the TWCF budget and drives higher cost recovery rates to customers. The USTRANSCOM continues to pursue cost reductions and more efficient operations to offset these budget risks. The TWCF budget incorporates a risk factor in its budget by assuming a greater degree of unknown contingency workload demand from customers. Additionally, USTRANSCOM is pursuing workload from non-traditional customers, such as foreign military sales and large weapon system contracts like the F-35 Joint Strike Fighter.

The USTRANSCOM's readiness is inextricably linked to Service-readiness management strategies and fiscal priorities. The Air Force's FY 2017 procurement budget request secures USTRANSCOM's ability to execute effective airlift and air refueling missions in future years. This includes funding for the flying hour and weapon system accounts, the modernization efforts and fielding of the C-5M Super Galaxy strategic airlifter, the C-130J Super Hercules theater airlifter, and the KC-46 Pegasus tanker. These initiatives are key to ensuring USTRANSCOM's ability to provide global reach and maintain strategic agility in the future as older weapon aircraft, such as the 1950's vintage KC-135 tankers, age. Further, the Navy is applying funds towards procuring the first wave of the updated sealift fleet, beginning with the T-AO (X)

Overview – FY 2017 Defense Budget

platform. The Army and Navy MILCON budgets contain funding for strategic seaports, enabling USTRANSCOM to effectively operate its global enroute system.

Building on Service Capabilities: Joint Training

The Military Departments must regularly train and exercise together to operate effectively as a Joint Force. This includes active participation in combatant command-sponsored large force exercises as well as innovative, low-cost, small-footprint engagements across the globe. Participation enables the Military Departments to develop regional expertise and build trusting relationships with each other, U.S. allies, and international partners, while developing the joint operational experience that is essential for success in today's global security environment.

Combatant Command Exercise and Engagement

Each Military Department's readiness program produces a set of building blocks that make up the Joint Force. The FY 2017 budget request includes \$157 million in FY 2017 for joint training enablers through the Combatant Commander Exercise Engagement and Training Transformation (CE2T2) program to cement these building blocks into a ready and cohesive Joint Force. Building on Military Department-specific training and readiness capabilities, the CE2T2 program helps close Service-training deficiencies that exist in the seams between the tactical and operational levels of war. Additionally, the program funds joint training enablers in the "no man's land" between the Military Departments' training and joint operating force training.

For example, the CE2T2 program funds the Joint Training Enterprise Network (JTEN), a system that links the geographically-separated live, virtual, and constructive training capabilities of the combatant commands and Military Departments and integrates them into a realistic joint training environment. The JTEN bridges the gap between tactical and operational level training and mission rehearsal activities by providing real-time connectivity and simulations of higher headquarter authorities.

Another program funded by CE2T2 is the Joint Training Coordination Program (JTCP), which enables the live participation of one Military Department's assets in the tactical-level exercises of another Military Department. Specific exercises receiving JTCP funding in FY 2017 include: the Air Force's RED FLAG and GREEN FLAG exercises held at Nellis Air Force Base, NV; the Navy's Fleet Readiness exercise held at Air Wing Fallon, NV; the Marine Corps' Tactical Operations Group Exercise held at Twenty Nine Palms, CA; and the Army's National Training Center Program events in Fort Irwin, CA. These joint training venues prepare the Military Departments for the tactics used in ongoing operations in Afghanistan, Libya, Syria, Africa, and other theaters across the globe.

Other joint training opportunities funded through the CE2T2 program include: joint individual training that prepares service members to operate in a joint environment; Service-unique training simulations that allow them to operate in a realistic joint environment and with U.S. international partners; replication of robust opposing forces (OPFOR) that optimize training on Military Department tactical ranges for both the host Military Department and other Military Department participants; and development of a virtual training environment that facilitates 24/7 online joint training from the individual to the joint task force level.

The FY 2017 budget request includes funding to support the exercises and engagement requirements of the nine combatant commands. These events improve the readiness of the force to conduct joint operations, highlight U.S. capabilities, deter potential adversaries, and build partner capacity. For the combatant commands, exercise and engagement events are a cost-effective way to provide U.S. presence, reassure allies, and hedge against destabilization in high-risk areas. More specifically, this funding supports over 100 major exercises annually that prepare U.S. forces to execute operational plans, train the combatant command staffs,

Overview – FY 2017 Defense Budget

provide presence and regional expertise with U.S. allies and partners, and build relationships and trust.

FY 2017 Joint Exercise Program Authorized, CE2-Funded Exercises

- U.S. Africa Command (USAFRICOM): EPIC GUARDIAN — USAFRICOM/SOCAFRICA ELLIPSE GOLF exercise. A Global Command and Control level exercise designed to rehearse and validate procedures for a select contingency plan, and mature possible responses and task force interaction. The exercise covers a broad range of topics, including logistics, intelligence, and public affairs.
- U.S. Central Command (USCENTCOM): EAGER LION — A USCENTCOM-executed multi-lateral exercise to improve the ability of coalition forces to prevent, prepare for, respond to, and mitigate a crisis resulting from a natural or man-made disaster.
- U.S. European Command (USEUCOM): SABER STRIKE — A U.S. Army Europe led company-level live fire exercise and brigade/battalion-level command post exercise designed to sustain the interoperability of U.S. and Baltic partners when forward deployed in support of NATO or other multilateral contingency operations.
- USEUCOM: TRIDENT JUNCTURE (TRJE) — A NATO Supreme Allied Commander, Transformation-sponsored command post exercise. Recent scenarios involved a multinational force deployed in a NATO Non-Article 5 crisis response operation and included the participation of select elements of the U.S. Global Response Force, and linked USTRANSCOM's ULTIMATE REACH exercise.
- U.S. Northern Command (USNORTHCOM)/North American Aerospace Defense Command (NORAD): VIGILANT SHIELD — A Joint Exercise Program Tier 1 exercise event, supported by the Joint Staff and conducted as a command post exercise, designed to train USNORTHCOM/NORAD HQ staffs in Homeland Defense/Homeland Security process interaction; tentatively to be linked to Canadian Joint Operations Command DETERMINED DRAGON 16.
- U.S. Pacific Command (USPACOM): PACIFIC SENTRY — Exercise focused on operation/contingency plan execution. It is conducted in three iterations annually: a senior leader seminar, a targeting focused command post exercise, and separately, a more broadly oriented command post exercise.
- USPACOM: ULCHI FREEDOM GUARDIAN — A bilateral exercise focused on USPACOM and U.S. Forces Korea/Combined Forces Command operational plans supporting the defense of the Republic of Korea. It examines the strategic, operational, and tactical aspects of military operations in the Korean theater of operations.
- U.S. Southern Command (USSOUTHCOM): PANAMAX — USSOUTHCOM's largest engagement exercise typically involving over 16 partner nations and more than 300 participants from those partner armed forces. The PANAMAX trains the battle staff and subordinate component commands in conducting multi-national operations aimed at countering a wide range of threats in the Panama Canal region.
- U.S. Strategic Command (USSTRATCOM): CYBER GUARD — A “Whole of Nation” cyberspace training exercise focused on responding rapidly to an effective domestic cyber-attack, catastrophic natural or man-made cyberspace disruption.
- USSTRATCOM: CYBER FLAG — A tactically-focused joint exercise fusing offensive and defensive cyberspace operations with DoD full-spectrum combined arms operations against capable and thinking adversaries in a realistic virtual environment.

Overview – FY 2017 Defense Budget

- USSTRATCOM: GLOBAL THUNDER — A strategic battle staff readiness training event designed to maintain battle staff critical task proficiency as the exercise scenario begins with a conventional attack and evolves toward nuclear operations. The GT is designed to exercise all the mission areas assigned to USTRATCOM.
- USSTRATCOM: TURBO CHALLENGE — A primary battle staff command post exercise, linked annually to a supported geographic and/or functional combatant command joint exercise to exercise USTRANSCOM's unique responsibilities as assigned within the President's Unified Command Plan. The TC exercises existing and conceptual USTRANSCOM plans, policies, procedures, and systems to evaluate command proficiency on accomplishing existing joint mission essential tasks.
- U.S. Transportation Command (USTRANSCOM): ULTIMATE GUARDIAN 2017 (UG 17) — A cyber exercise, to be linked with USPACOM's PACIFIC SENTRY 17-2. The UG 17 will exercise and assess USTRANSCOM, its transportation component commands (TCCs), and subordinate commands readiness for defensive cyberspace operations at the strategic, operational, and tactical levels. The exercise will involve detection, reporting, mitigation, recovery processes and procedures, and exploring command and control relationships with supporting cyber mission forces.

Joint Logistics

The Joint Logistics Enterprise (JLEnt) continues to meet current operational requirements while remaining flexible to respond to new threats and challenges. Recent budget constraints forced the Military Departments to make tough choices with regard to force structure and force posture. In many cases these decisions affected critical logistics enablers reducing the JLEnt's ability to rapidly respond to contingencies. Additionally, continued operation under constrained resource conditions forces the Joint Force to choose to maintain current logistics readiness plans and programming over building future logistics capability and capacity. Consistent and predictable funding for ship and aviation depot level maintenance is necessary to optimize capacity and backlog. Projected FY 2017 funding levels can halt further decline, but the sequestration level funding caps could jeopardize a recovery glide path. Additionally, uncertain operational tempo could increase lifecycle usage, consume critical commodities, and change depot level maintenance planned requirements.

The FY 2017 budget request provides for the current logistics operational requirements but may fall short of adequately meeting the demands of future contingencies, logistics modernization, and readiness needs to shape Joint Force Next and beyond. The Joint Force will continue to focus on key partnerships that mitigate reduced flexibility and posture through building partner logistics capacity and improved host nation access. However, even these initiatives need adequate funding. The Department's need for the funding levels reflected in the FY 2017 FYDP is imperative to reduce further atrophy of readiness, mitigate risk, and properly resource to rebuild logistics capacity.

Language and Culture Capabilities

The FY 2017 budget request supports the importance of language, regional, and cultural understanding in building international partnerships as well as contributing to successful operational outcomes across the entire spectrum of operations. The Department has learned, after more than a decade of war, that a basic understanding of U.S. partners' language and culture is essential for the efficacy of the total force and not just for special operations and intelligence forces. The FY 2017 budget request funds several investments that increase the percentage of the force with foreign language and cultural competency, even as the size of the force declines. In 2013, slightly more than 336,500 personnel had language capabilities,

Overview – FY 2017 Defense Budget

roughly 10.49 percent. In 2014, the percentage grew to 10.74 percent, despite a decline of more than 63,000 personnel. In 2015, the percentage of the force with language skills was 10.76 percent, even though the total force was further reduced by more than 9,400 members. The Department's sustained commitment is expected to yield an increase to at least 10.80 percent by the end of FY 2017. Recruiting, training, and skill sustainment all contribute to the Department's commitment to ensuring the war fighters have the necessary language capabilities.

The Department's language and culture investments support all Federal departments and agencies. Specifically, the National Security Education Program is designed in statute to provide a future Federal workforce with skills in languages and cultures critical to national security. The FY 2017 budget request for this program reflects a \$26 million Department of Defense commitment, \$16 million of which is a transfer of funds from the Office of the Director of National Intelligence in accordance with 50 U.S.C. 1902. These efforts include partnerships with institutions of higher education, competitive scholarships and fellowships, and the development of recruiting and retention policies to increase the return on these investments. The Department also supports the National Language Service Corps, which provides language surge capacity across the entire Federal government, including the DoD. This Corps provides an effective hedge against the effects of uncertainty in current and future national security language needs.

The FY 2017 budget supports efforts to increase the capacity of language-enabled personnel, specifically within DoD. The budget includes funding for the Defense Language Institute Foreign Language Center (DLIFLC), the Department's primary training resource for intelligence community military professionals and General Purpose Forces (GPF) across the Department. In FY 2017, DLIFLC will continue efforts to raise language proficiency graduation standards to 2+ in both reading and listening. The FY 2017 budget request provides money to train more than 3,000 students in DLIFLC's basic courses in 24 languages and dialects. In addition, DLIFLC will provide continuing education for more than 4,800 language professionals and pre-deployment and familiarization training for more than 1,200 GPF personnel through Mobile Training Teams, Video-Tele training, and Language Training Detachments.

Beyond mobile training teams that provide "just-in-time" training for deploying personnel, the FY 2017 budget supports Language Training Centers (LTC) that partner between universities and the Department to provide language instruction. In FY 2015, nine institutions of higher education hosting LTCs provided training to approximately 1,500 DoD personnel in 17 languages and expanded collaborations with the National Guard and Special Forces community. This brings the LTC program's grand total to nearly 8,500 DoD personnel trained since its inception in 2011. A special LTC initiative was developed in 2015 to provide Foreign Area Officers with advanced understanding and analysis of the most current regional security affairs and the impact of regional activities on interagency and joint operations. A new LTC was selected for this initiative, which brings the total number of institutions of higher education in the LTC community to ten. The FY 2017 budget request also provides for pre-accession language training for military officer candidates enrolled at institutions of higher education through the Project Global Officer (GO) program. Project GO promotes critical language learning, study abroad, and intercultural exposure among Reserve Officer Training Corps (ROTC) students. Since its inception in 2007, over 3,500 ROTC students nationwide participated in the program. There are currently 25 institutions of higher education hosting Project GO programs, including five of the six Senior Military Colleges.

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4. ACCELERATE THE PACE OF DEFENSE REFORM

The Department, with assistance and support from Congress, embarked on a reform path in FY 2010. The FY 2017 budget request continues and expands reform efforts as detailed in this chapter.

By reworking the Department's command structure, Public Law 99-433, the Goldwater-Nichols Department of Defense Reorganization Act of 1986, made the most sweeping changes to the Department since it was established in the National Security Act of 1947. The Department has undertaken a comprehensive review of organizational issues spanning the Office of the Secretary of Defense, the Joint Staff, the combatant commands, and the Military Departments, with the objective of identifying potential redundancies, inefficiencies, and other areas for improvement. The review is ongoing and preliminary internal findings are expected in time to shape recommendations for FY 2018.

Commencing in FY 2012, the Department initiated a series of efforts to reduce the cost of doing business by identifying opportunities for management improvements and better use of resources in such areas as health care modernization, force structure changes, headquarters reductions, travel and acquisition reforms, and multiyear procurement. Many of these savings have been reinvested into higher priority military programs. Others have been used to accommodate lower defense budgets.

- FY 2010 – FY 2011 budgets: Focused on weapons programs, e.g., terminating F-22 fighter production and the VH-71 Presidential helicopter, ended C-17 production and stopped pursuit of a second engine for the Joint Strike Fighter.
- FY 2012 – FY 2013 budgets: Focus on DoD business operations, overhead activities and support functions, but plans included some changes in weapons programs. Also proposed military health care changes.
- FY 2014 budget: Continued focus on more effective use of resources, with greater emphasis on weapons programs and Military Construction.
- FY 2015 budget: More focus on contracting efficiencies, controlling health care costs, and reducing management headquarters.
- FY 2016 budget: Continued focus on improving the financial management workforce, improving audit readiness, contracting oversight, and improving technological superiority while controlling life cycle costs.
- FY 2017 budget: Continuing previous initiatives and enhancing focus on ensuring capabilities to achieve dominant capabilities on future battlefields while delivering better value to the taxpayer and warfighter by improving the way the Department does business; new initiatives in infrastructure and support activity reforms.

Major Themes

- Force Structure for Current and Future Operations
- Base Realignment and Closure
- Health Care Reform
- Infrastructure and Support Activity Reforms
- Better Buying Power: Obtaining Greater Efficiency and Productivity in Defense Spending
- Control Costs throughout the Product Life Cycle
- Financial Improvement and Audit Readiness Initiative
- Audit and Contract Management Oversight
- Improving the Financial Management Workforce

FORCE STRUCTURE FOR CURRENT AND FUTURE OPERATIONS

The FY 2017 budget request reflects critical decisions on force structure reforms that are vital to making sure U.S. military forces have the capabilities needed for both present and future missions. The FY 2017 budget request continues some force structure reductions from the FY 2015 and FY 2016 budgets and adjusts other force structure changes:

- The Army eliminates 1 National Guard Brigade Combat Team (BCT).
- The Navy decommissions 6 ships and activates 13 ships for a net increase of 7 ships to the inventory. In addition, the Navy is decommissioning the 10th Carrier Air Wing.
- The Marine Corps increases 1 active infantry battalion, which reflects a 1 year delay of their FY 2016 force structure plan.
- The Air Force is increasing by 1 Active Combat Coded Squadron due to retaining the A-10 Warthog aircraft.

The Department plans to reduce the total military end strength by 29,200 (a 1.4 percent reduction) from 2.11 million in FY 2016 to 2.08 million in FY 2017. Additional end strength and force structure reductions will be needed if sequestration level funding returns in FY 2018.

BASE REALIGNMENT AND CLOSURE (BRAC)

The force structure that emerges from the new defense strategy will require a properly aligned infrastructure from which to operate, deploy, and train. Further, underutilized military facilities create a drag on the economies of their host communities and prevent the Department from redirecting its scarce resources from facility maintenance to its readiness objectives. The NDAA for FY 2016 required the Department to produce a new analysis to demonstrate its excess capacity; that analysis is underway. The Department therefore requests Congress to authorize a new BRAC round in 2019, using the established statutory process that has proven, repeatedly, to be the only effective and fair way to eliminate excess infrastructure and reconfigure what must remain. A key component of this proven process is having an independent commission that provides third-party review, validating or even changing the Department's recommendations.

The FY 2017 budget request includes \$4.0 million in FY 2017 for planning and oversight. Prior BRAC rounds are producing \$12.5 billion in annual savings. The need to reduce unneeded facilities is so critical that, in the absence of authorization of a new round of BRAC, the Department will explore any and all authorities that Congress has provided to eliminate wasteful infrastructure.

HEALTH CARE REFORM

The Department has submitted several reform plans since 2005, largely to control health care costs. The FY 2016 benefit reform proposal was relatively well received based on its greater simplicity and a perceived increase in value that corresponded to a modest cost increase. The PB 2017 health benefit reform proposal leverages the FY 2016 proposal but makes some important adjustments. Chapter 6, Taking Care of People, of this document includes more information regarding reforms to the TRICARE health program and the military retirement system. The attributes of the FY 2017 proposal include:

- A simpler system that provides beneficiaries with two care alternatives and less complexity in the health plan. TRICARE Select is an HMO-like (managed) option that is

Overview – FY 2017 Defense Budget

Military Treatment Facility (MTF)-centric and TRICARE Choice is a preferred provider-like (unmanaged) option offering greater choice at a modestly higher cost.

- Emphasizes TRICARE Select, leveraging MTFs as the lowest cost option for care to make full use of capacity and provide needed readiness training workload for military providers.
- No change for Active Duty, who would maintain priority access to health care without any cost sharing but would still require authorization for civilian care.
- Copays, designed to minimize overutilization of costly care venues, will depend on beneficiary category (excluding active duty) and care venue. To facilitate the effective use of military clinics and hospitals and thereby improve the efficiency of DoD's fixed facility cost structure, MTFs would not charge copays. There would be fixed network copays for the TRICARE Choice option without a deductible.
- Participation fee for retirees (not medically retired), their families, and survivors of retirees (except survivors of those who died on active duty), who would pay an annual participation fee or forfeit coverage for the plan year. No participation fee for active duty or their family members. There is a higher participation fee for those retirees choosing the TRICARE Choice option (\$200 higher).
- Open season enrollment, similar to most commercial plans; participants must enroll for a 1-year period of coverage or lose the opportunity.
- Catastrophic caps, which have not gone up in 10 years, would increase slightly but still remain sufficiently low to protect beneficiaries from financial hardship. The participation fee would no longer count towards the cap.
- Parity with Active Duty Family Members for medically retired members and their families and survivors of those who died on active duty; no participation fee and lower cost shares.
- To ensure equity among Active Duty Family Members (ADFM), the proposal offers all ADFMs a no cost care option regardless of assignment location and zero copays for ADFM ER use, including in the network.
- The Department will offer a second payer option with a lower fee for those with other health insurance.
- Fees and copays will be indexed at the National Health Expenditures (NHE) per capita rate.

INFRASTRUCTURE AND SUPPORT ACTIVITY REFORMS

The Department continuously reviews infrastructure and support activities to identify organizational and process improvements that can reduce costs, increase efficiency, and free up resources needed for the readiness and modernization of the force. These initiatives, taken together, are expected to yield approximately \$7.7 billion in savings over the Future Years Defense Program (FYDP), as summarized in Figure 4-1. Initiatives include:

- Major Headquarters Activities (MHA) Reduction: For the Office of the Secretary of Defense and the Defense agencies, the Department is undertaking a comprehensive “delaying” review, applying organizational principles developed in the private sector and applied successfully by the Army and the Air Force, to improve organizational alignment and meet the reduction target. The objective, now codified in the NDAA for

Overview – FY 2017 Defense Budget

FY 2016, is to reduce funding for major headquarters activities by 25 percent over the FYDP.

- Service Requirement Review Boards (SRRBs): The SRRB process entails review and rationalization of service contracts across the Office of the Secretary of Defense, the Defense Agencies, and Field Activities (the Fourth Estate). The SRRB process has been successfully applied by the Military Departments. By 2021, DoD expects to realize savings of \$1.9 billion in Fourth Estate entities funded by direct appropriations, and additional savings in the working capital funded entities.
- Business Operations Improvements: The Department is implementing a plan for more disciplined implementation of business systems improvements to achieve a better return on information technology investments. Review of existing Fourth Estate investments and investments in military integrated personnel and pay systems is projected to achieve savings of about \$0.6 billion across the FYDP. In addition, the Department projects savings of about \$0.5 billion through defense travel modernization.
- Information Technology (IT) Optimization: The Department plans to achieve significant savings in IT through circuit optimization, leveraging purchasing power in enterprise licensing agreements, ensuring more efficient utilization of data center infrastructure, and consolidating IT in the National Capitol Region.
- Defense Resale Business Optimization: The Department is developing a comprehensive strategy to pursue operational efficiencies, optimize and promote common practices, and garner savings across the entire Defense resale system, comprised of the defense commissaries and the military exchanges. With the assistance of new legislative flexibility provided in the NDAA for FY 2016 and additional flexibilities requested for FY 2017, the Department expects to achieve savings of \$1.9 billion over the FYDP without any reduction to patron benefits.

Figure 4-1. Initiatives and Process Improvements

(Dollars in Billions, Base Budget only)

	FY 2017	FY 2018-FY 2021
Management Headquarters Reduction	0.15	1.5
Service Requirements Review Boards	0.14	1.9
Business Operations	0.04	1.1
IT Optimization	0.06	1.3
Defense Resale Business Optimization	--	1.9
Total	0.40	7.7

Numbers may not add due to rounding

BETTER BUYING POWER: OBTAINING GREATER EFFICIENCY AND PRODUCTIVITY IN DEFENSE SPENDING

A central tenet of the Department's efforts to continuously improve the productivity of the Government and the Industrial Base in delivering better value to the taxpayer and warfighters is the ability to achieve greater efficiencies in the defense acquisition enterprise. First introduced in 2010, Better Buying Power (BBP) has evolved from an emphasis on basic acquisition principles and best practices under the original BBP 1.0, to a focus on critical thinking and sound professional judgment captured in BBP 2.0, to an emphasis on achieving dominant capabilities through technical excellence reflected in BBP 3.0.

Overview – FY 2017 Defense Budget

Better Buying Power 3.0 encompasses eight focus areas:

- Achieve affordable programs;
- Achieve dominant capabilities while controlling lifecycle costs;
- Incentivize productivity in industry and government;
- Incentivize innovation in industry and government;
- Eliminate unproductive processes and bureaucracy;
- Promote effective competition;
- Improve tradecraft in acquisition of services; and
- Improve the professionalism of the total acquisition workforce

Many of the BBP 3.0 initiatives address technical excellence and innovation. Examples include:

- Increase the use of prototyping and experimentation;
- Emphasize technology insertion and refresh in program planning;
- Use Modular Open Systems Architecture to stimulate innovation;
- Provide clear “best value” definitions so industry can respond; and
- Strengthen organic engineering capabilities

Underpinning BBP 3.0 is the growing concern that the nation’s technological superiority over potential adversaries is being threatened today in a way not seen for decades. The U.S. military today depends on a suite of dominant capabilities that originated in the 1970s and 1980s. These capabilities have been enhanced and upgraded since that time, but have not fundamentally changed. The DoD’s technological superiority is not assured and, in fact, it is being increasingly challenged.

This release of BBP 3.0 does not end DoD’s focus on controlling costs, critical thinking, and sound professional management. It shifts the Department’s emphasis toward ensuring capabilities to achieve dominant capabilities on future battlefields. The focus of BBP remains delivering better value to the taxpayer and warfighter by improving the way the Department does business, while addressing both the fiscal and security challenges that face the nation.

CONTROL COSTS THROUGHOUT THE PRODUCT LIFE CYCLE

Cost control starts with clear, accurate, prioritized requirements, followed by buying the most cost-effective performance needed to accomplish the mission. The Department will continue to align the communication between the requirements and acquisition communities to ensure the highest likelihood of success. Product life cycles typically last for decades, and requirements and acquisition decisions will influence the Department’s costs well into the future. Today’s design decisions for systems in development affect tomorrow’s costs for sustainment. The Operating and Support Cost Key System Attribute, which is a requirement for all new programs, makes life cycle cost control an imperative that begins at program inception.

The Department has implemented a requirement for affordability analysis and constraints on programs as one means of controlling costs throughout the life cycle. Assessing the affordability of major systems before, during, and after production establishes the fiscal feasibility of the program, informs the Analyses of Alternatives, guides capability requirements and engineering tradeoffs, sets realistic program baselines, and enables executable

sustainment planning. The analysis includes a quantitative assessment across capability portfolios, rather than just for specific programs. To assess the ability to fund the program over its life cycle within expected budget levels, affordability analysis looks at the entirety of the program's costs rather than near-term budget years.

Additional work is needed beyond this affordability analysis as the Department acquires and sustains new capabilities. "Should Cost" management is an approach to cost control that requires managers to understand and when possible reduce costs under their control. The Department is aggressively employing the use of Should Cost management for acquisition programs during sustainment as well as during acquisition. During program reviews, Program Managers for Acquisition Category 1 programs specifically report their Should Cost targets and progress toward achieving them.

Cost control efforts continue after the production phase. Once a weapon system is fielded, the program's primary means of cost control is through execution of its sustainment plan. Given the long timeframes for sustainment, often decades, and shifting circumstances under which a system may be employed, the Department requires program managers to assess and update sustainment plans continually and to identify opportunities for cost reduction throughout the product's service life.

FINANCIAL IMPROVEMENT AND AUDIT READINESS INITIATIVE

The Financial Improvement and Audit Readiness (FIAR) initiative is the Department's strategy for achieving and validating audit readiness of all financial statements by September 30, 2017. Audit readiness means the Department has strengthened its internal controls and improved its financial practices, processes, and systems, so there is reasonable confidence that the information can withstand an audit by an independent auditor.

Fiscal year (FY) 2015 was a pivotal year for the Department. Each Military Department commissioned an Independent Public Accountant (IPA) firm to conduct a limited-scope audit of its General Fund Schedule of Budgetary Activity (SBA) for its FY 2015 appropriations. Additionally, most of the larger other Defense organizations (ODO) went under SBA examination or completed mock audits of their current year budgetary activities. Going under IPA audit or examination is an essential part of the Department's FIAR strategy and is consistent with the generally positive feedback on this approach, received from Government Accountability Office (GAO), the Department of Defense Office of the Inspector General (DoD IG), and some members of Congress. Audits highlight remaining deficiencies and dependencies between organizations so corrective actions can be implemented and full audit readiness can be achieved. Going under audit also means an important culture change is underway, requiring military and civilian personnel across the Department to learn and understand the responsibilities associated with achieving and sustaining auditability.

During FY 2015, about 90 percent of the Department's current year General Fund appropriations were under audit. The General Fund appropriations not currently under audit are undergoing examinations or audit readiness activities. Over the next 2 years, the Department will continue to expand the scope of audits while continuing these examinations and audit readiness activities to sustain a stronger, more disciplined business environment until full audit readiness is achieved. Lessons learned from other Federal agencies suggest that the first years of auditing the full financial statements will not result in a positive opinion, but the Department is committed to resolving all issues until a positive opinion can be achieved and sustained.

AUDIT AND CONTRACT MANAGEMENT OVERSIGHT

The Department provides independent contract audits and management support to the Military Services and Defense Agencies to ensure that the contracts that the Department enters into are priced fairly and that the Department and the taxpayer receive agreed upon products and services. Three agencies provide these services: (1) the Defense Contract Audit Agency (DCAA); (2) the Defense Contract Management Agency (DCMA); and (3) the Office of the Inspector General (OIG). Figure 4-2 provides the funding and civilian manpower for each of these organizations.

Figure 4-2. Contract Management and Oversight

(Dollars in Billions, Base Budget only FY 2016/2017, Direct FTEs in whole numbers)

Program	FY 2015 Actuals*	FY 2016 Enacted	FY 2017 Request
Defense Contract Audit Agency	\$0.6	\$0.6	\$0.6
DCAA Direct Full-Time-Equivalents	4,230	4,080	4,632
Defense Contract Management Agency	\$1.3	\$1.4	\$1.4
DCMA Direct Full-Time-Equivalents	10,023	10,286	10,466
Office of Inspector General	\$0.3	\$0.3	\$0.3
OIG Direct Full-Time-Equivalents	1,495	1,507	1,587
Total – Audit and Contract Management	\$2.1	\$2.2	\$2.3
Total Civilian Full-Time-Equivalents	16,770	16,803	17,642

The establishment of the DCAA (1965) and DCMA (2000) consolidated the audit and contract management functions, previously performed by the Military Services, into independent organizations that now apply consistent and methodical audit, contract management, and assessment regulations and principles across the Department.

- The DCAA performs contract audit functions for all DoD Components plus other Federal agencies. In FY 2015, the DCAA audited nearly \$175 billion of costs incurred on contracts and issued about 880 forward pricing proposal audit reports totaling about \$62.5 billion. In FY 2015, DCAA achieved \$3.1 billion in savings as the result of audit findings
 - In FY 2017, the DCAA continues efforts to reduce the incurred cost backlog, maintain an incurred cost inventory at an acceptable level, and meet DoD's other mission critical audit needs. Reducing the backlog will: (1) assist in achieving auditable financial statements; (2) assist the Department in closing completed contracts; and (3) prevent undue delays in payments of fees to contractors (a portion of fees to contractors is delayed until the contract is closed)
- The DCMA represents the Military Services, other Federal agencies, and related government buying agencies at defense contractor locations worldwide, prior to and after contract award. The DCMA provides Contract Advisory Services on more than 345,000 prime contracts with a total value of more than \$1.9 trillion, which is performed by over 19,600 contractors

Overview – FY 2017 Defense Budget

- In FY 2017, the DCMA continues the Department's efforts to grow the acquisition workforce to mitigate known acquisition oversight workforce shortfalls, primarily in the areas of price costing, earned value, and quality assurance
- Created by the Inspector General Act of 1978, the DoD OIG is an independent, objective agency within the Department of Defense. The DoD OIG is responsible for conducting audits, investigations, and inspections, and recommends policy and procedure changes to promote economic, efficient, and effective use of agency resources and programs that prevent fraud, waste, abuse, and mismanagement. In FY 2015, the DoD OIG identified \$2.5 billion in potential monetary benefits and recovery
- In FY 2017, the OIG will continue its efforts in serving the warfighter, and the taxpayer, by conducting audits, investigations, inspections, and assessments that provide guidance and recommendations for both the Department and Congress

IMPROVING THE FINANCIAL MANAGEMENT WORKFORCE

The Department requires a well-trained financial management workforce to achieve auditable financial statements and provide strong financial management. The National Defense Authorization Act (NDAA) for Fiscal Year 2012 (Public Law 112-8) provided the authority for DoD to prescribe certification and credentialing standards for the financial management community. The Department initiated a multiyear effort to develop a course-based Financial Management (FM) Certification Program. The Program applies to personnel in the FM workforce and offers training and professional opportunities while establishing a standard financial management body of knowledge throughout the Department. This effort has been supported by the U.S. House of Representatives, the Senate, and the Government Accountability Office.

The Certification Program aims to move the FM workforce toward a more analytical orientation and helps to ensure the FM workforce has the knowledge necessary to achieve auditable financial statements. It also establishes a DoD FM framework to guide the professional development of approximately 54,000 members of the FM workforce and ensures the workforce has the competencies to adapt to future mission requirements. Through increased training in key areas such as audit readiness, the program supports the Department's effort to achieve auditable financial statements by 2017 as directed by the Secretary of Defense and the Congress. Identifying and defining key competencies in both FM and leadership enables the Department to assess and close gaps between current capabilities and the competencies required by the future financial management workforce. Once they achieve certification, individuals must earn a minimum level of continuing education and training credits every 2 years to sustain their achieved certification level and maintain and improve financial management proficiency and skills.

The DoD FM Certification Program policy was signed on November 20, 2013. Initial implementation for civilians and active duty Components was completed in September 2014, and implementation of the Guard and Reserve Components was completed in March 2015.

5. PURSUE INVESTMENTS IN MILITARY CAPABILITIES

Acquisition Summary

The Department maintains a healthy Science and Technology (S&T) program of \$12.5 billion to invest in future technologies. The overall Research, Development, Test, and Evaluation (RDT&E) portfolio of \$71.8 billion includes an increase of \$2.8 billion compared to the enacted FY 2016 appropriations. The procurement portfolio of \$112.1 billion includes \$0.1 billion for the National Guard and Reserve Equipment and a decrease of \$7.0 billion from the enacted FY 2016 appropriations.

Key Initiatives

- Space and Space-Based Systems
- Missile Defense Programs
- Cyberspace Operations
- Science & Technology

Figure 5-1. Investments

Base and OCO \$ in billions

	FY 2016 Enacted	FY 2017 Request	Change
Aircraft and Related Systems	50.6	45.3	-5.3
C4I Systems	7.1	7.4	0.3
Ground Systems	9.9	9.8	-0.1
Missile Defense Programs	9.1	8.5	-0.6
Missiles and Munitions	12.7	13.9	1.2
Mission Support	52.9	52.4	-0.5
Science & Technology (S&T)	13.0	12.5	-0.5
Shipbuilding and Maritime Systems	27.5	27.0	-0.5
Space-Based Systems	7.0	7.1	0.1
Rescissions	-1.8	-	+1.8
Total	188.0	183.9	-4.1

Major Weapons Programs

The Department pursues numerous major weapons programs. Some are described in later portions of this section; others are described in the Military Departments' summaries presented in Chapter 8 of this document. Figure 5-2 summarizes the top 25 DoD weapon programs as measured by their total procurement and RDT&E funding in the FY 2017 budget. The website displays the Department's "Program Acquisition Costs by Weapons Systems" book (<http://comptroller.defense.gov/budgetmaterials/budget2014.aspx#press>) that provides more detailed information.

Overview – FY 2017 Defense Budget

Figure 5-2. Major Acquisition Programs

Base and OCO \$ in Billions; Includes RDT&E and Procurement funding

		FY 2016		FY 2017	
		Qty	\$	Qty	\$
Aircraft					
F-35	Joint Strike Fighter	68	11.6	63	10.5
KC-46A	Tanker	12	3.0	15	3.3
P-8A	Poseidon	17	3.4	11	2.2
V-22	Osprey	20	1.6	16	1.5
E-2D AHE	Advanced Hawkeye	5	1.2	6	1.4
AH-64E	Apache Helicopter	64	1.4	52	1.1
C/HC/MC-130J	Hercules	29	2.4	14	1.3
UH-60	Black Hawk Helicopter	107	1.8	36	1.0
CH-53K	King Stallion Helicopter	--	0.6	2	0.8
MQ-4C	Triton	4	1.0	2	0.8
H-1 Upgrades	Bell Helicopter	29	0.9	24	0.8
NGJ	Next Generation Jammer Increment 1	--	0.4	--	0.6
CH-47F	Chinook Helicopter	39	1.1	22	0.7
Missile Defense/Missiles					
BMDs	Ballistic Missile Defense	--	7.7	--	6.9
Trident II	Trident II Missile Mods	--	1.2	--	1.2
AMRAAM	Adv. Medium Range Air-Air Missile	429	0.7	419	0.7
Ships					
SSN 774	VIRGINIA Submarine	2	5.7	2	5.3
DDG 51	AEGIS Destroyer	2	4.4	2	3.5
CVN 78	FORD Aircraft Carrier	--	2.8	--	2.8
ORR	Ohio Replacement	--	1.4	--	1.9
LHA-6	Amphibious Assault Ship	--	.5	1	1.6
LCS	Littoral Combat Ship	3	1.8	2	1.6
Space					
AEHF	AEHF Satellite	--	0.6	--	0.9
EELV	EELV Launch Vehicle	4	1.5	5	1.8
Trucks					
JLTV	Joint Light Tactical Vehicle	804	0.4	2,020	0.7

SPACE AND SPACE-BASED SYSTEMS

The FY 2017 budget request includes \$7.1 billion for the DoD Space Investment Programs, which reflects an increase of \$0.1 billion above the FY 2016 enacted level of \$7.0 billion. For FY 2017, the Department continues to modify the space program portfolio based on the Space Strategic Portfolio Review, which recommended strategic goals and capabilities to implement an

Overview – FY 2017 Defense Budget

assured spaces strategy. The budget allows the United States to maintain supremacy in space and provides communications, navigation, missile warning, space situational awareness, and environmental monitoring capabilities.

The Air Force completes Global Positioning System (GPS) III space vehicles (SV) 01 and 02 for available launch activities and updates the procurement profile to position the program for a potential follow-on competition to procure SV 11-32. The Air Force continues the development of the GPS Operational Control System (Blocks 1 and 2) and the Military GPS User Equipment Increment 1. The Air Force also funds the GPS Prime Integrator (Enterprise Integration) effort to synchronize space control and user segment programs and manage civil/military specifications and requirements.

The Air Force continues to explore an alternative architecture for Satellite Communications (SATCOM) and Overhead Persistent Infrared (OPIR). The FY 2017 budget request also sustains the existing SATCOM and OPIR systems through the transition, maintaining the Advanced Extremely High Frequency capability with vehicles 5/6 through 2027 and the Space-Based Infrared System geosynchronous orbit capability with vehicles 5/6 through 2025.

The Air Force is exploring cost-effective acquisition approaches for meeting the Department's future space based environmental monitoring (SBEM) capabilities. The request includes funding for the Weather System Follow-On (WSF), which will begin during in FY 2016. The FY 2017 budget request includes a reduction in scope for the Defense Meteorological Satellite Program (DMSP) to include only sustainment of the on-orbit constellation and divestment of Flight 20. The Department's overall SBEM approach leverages civil and partnerships while investing in WSF to meet DoD requirements.

The Evolved Expendable Launch Vehicle (EELV) program has been aligned with satellite launch schedules in FY 2017 while aggressively pursuing competition. The FY 2017 budget request also continues the block buy of five EELV launch services, three of which are set aside for competition and usually ordered 24 months prior to the planned mission, as well as activities such as launch preparation, site and operations activities, post mission analysis, and related tasks. The Air Force is taking steps to ensure the existence of two commercially-viable, domestically-sourced space launch service providers with the objective of also eliminating reliance on a foreign-made liquid rocket engine. The Air Force is also planning one or more Public-Private Partnership ventures for these efforts, which may include new upper stages as part of the development effort. The Air Force certified SpaceX as an EELV provider on May 19, 2015.

The FY 2016 budget request established a new account for Air Force major space procurement programs. The Congress approved the new space appropriation; however, in the Statement of Managers for the Consolidated Appropriations Act for 2016, the Congress directed that all space-related procurement line items should be included in this new appropriation. Therefore, the FY 2017 budget request transfers all space-related items requested in Other Procurement, Air Force appropriation to the Space Procurement, Air Force appropriation. The FY 2017 budget requests 5-year availability for the Space Procurement, Air Force account. Although it is reasonable and appropriate for the overwhelming majority of acquisition programs to have a 3-year period of availability (POA), modern satellites are highly complex and can take up to a decade to design and build. The long development and production timelines are more like those of large Navy ships, which are funded in the Shipbuilding and Conversion, Navy appropriation with a base POA of 5 years. The additional 2 years for the Space appropriation would provide time for obligations for engineering services, test and evaluation, and other activities that must be performed in the final stages of satellite development; thus, a 5-year POA would make the funds available for obligation for the duration of development and production.

MISSILE DEFENSE PROGRAMS

The FY 2017 budget request funds the development and deployment of ballistic missile defense (BMD) capabilities to support the Administration's commitment to protect the U.S. homeland, deployed forces, allies, and partners. The FY 2017 budget request for missile defense is \$9.1 billion, which includes \$7.5 billion for the Missile Defense Agency and reflects a decrease of \$.7 billion below the FY 2016 enacted level of \$9.8 billion.

For homeland defense, the FY 2017 budget request maintains the commitment to increase the number of deployed Ground-Based Interceptors (GBI) to 44 (by delivering an additional 14 interceptors over the FY 2016 level of 30 fielded interceptors); continue development of the Redesigned Kill Vehicle (REKV); and proceed with the development of the Long-Range Discrimination Radar (LRDR). When combined with the planned GBI reliability, system engineering, and discrimination improvements, these enhancements will enable the missile defense system to deal effectively with the Intercontinental Ballistic Missile (ICBM) threat from North Korea and a potential ICBM threat from Iran.

The FY 2017 budget request also reflects the Department's commitment to building the regional missile defense forces that are interoperable with the North Atlantic Treaty Organization (NATO) Air Command and Control and Patriot Systems, Israeli Arrow and Patriot Weapon Systems, and Japan Aerospace Defense Ground Environment (JADGE), and Aegis Weapon Systems and SM-3 interceptors deployed by international partners.

The Department continues to support the European Phased Adaptive Approach (EPAA), which is designed to protect U.S. deployed forces and allies in Europe from ballistic missile attacks from the Middle East. The FY 2017 budget request supports the implementation of Phase 3 of the EPAA, to include the deployment of Aegis Ashore to Poland in the FY 2018 timeframe. The Aegis Ashore will be capable of launching Standard Missile-3 (SM-3) Blocks IA, IB, and IIA (delivery in 2018) variants.

The FY 2017 budget request also:

- Provides additional funding for key capabilities to meet the maturing threat from North Korean ICBMs and the potential threat from Iranian ICBMs, including GBI reliability and system engineering enhancements, GBI modifications to address the root causes of previous flight test failures, and operation of the Sea-Based X-band radar;
- Provides funding for advanced technologies to meet the future threat, including discrimination improvements, directed energy research, and multiple kill technologies;
- Provides funding for Terminal High Altitude Area Defense (THAAD) concept development and risk reduction activities for follow-on capabilities; and procures 24 THAAD interceptors in FY 2017;
- Procures 85 new Missile Segment Enhancement (MSE) missiles. The MSE is a significant evolutionary improvement over the Patriot Advanced Capability-3 (PAC-3) missile, and provides greater agility and lethality;
- Continues U.S. contributions to the Iron Dome system to defeat short-range missiles and rockets; continues support for the Arrow Weapon System, Israeli Upper Tier Interceptors, and the David's Sling Weapon System; and
- Continues conversion of Aegis ships to provide BMD capability and procures 35 SM-3 Block IB missiles to be deployed on Aegis BMD ships and at the Romania Aegis Ashore site.

CYBERSPACE OPERATIONS

The FY 2017 base budget request of \$6.7 billion for cyber operations represents an increase in cyber funding of \$0.9 billion compared to the FY 2016 enacted base budget, and fully supports the Department's defensive and offensive cyberspace operations capabilities and cyber strategy.

The Department developed the 2015 DoD Cyber Strategy in response to the growing cybersecurity threats and to guide efforts to defend the Nation against cyberattacks of significant consequence. The new cyber strategy, the Department's second, guides the development of DoD's cyber forces and strengthens its cybersecurity and cyber deterrence posture.

The strategy focuses on building cyber capabilities and organizations for DoD's three primary cyber missions: to defend DoD networks, systems, and information; defend the Nation against cyberattacks of significant consequence; and provide cyber support to operational and contingency plans. To accomplish these missions, the strategy sets five strategic goals:

1. Build and maintain ready forces and capabilities to conduct cyberspace operations;
2. Defend the DoD information network, secure DoD data, and mitigate risks to DoD missions;
3. Prepare to defend the U.S. homeland and U.S. vital interests from disruptive or destructive cyberattacks of significant consequence;
4. Build and maintain viable cyber options and plan to use those options to control conflict escalation and to shape the conflict environment at all stages; and,
5. Build and maintain robust international alliances and partnerships to deter shared threats and increase international security and stability

The Department's FY 2017 budget:

- Continues to organize the 133 team Cyber Mission Force, which is expected to be fully operational by the end of FY 2018;
- Outfits the new Joint Operations Center for U.S. Cyber Command (USCYBERCOM) at Fort Meade, Maryland; occupancy is scheduled for FY 2018;
- Continues to support cyberspace operational Science and Technology programs and other research and technology projects to develop the tools required by the Cyber Mission Force to accomplish its mission;
- Continues to develop innovative approaches to provide a virtual environment for the Cyber Mission Force to consistently train and mission rehearse across a wide range of threat environments;
- Continues to support defensive cyberspace operations by providing information assurance and cyber security to the Department's networks at all levels, and via ongoing investments in the Department's larger Information Technology budget to implement Joint Regional Security Stacks across the DoD enterprise; and
- Continues to support Combatant Commanders and offensive cyber operations by providing integrated cyber capabilities to support military operations and contingencies.

SCIENCE & TECHNOLOGY

The Department's Science and Technology (S&T) Program's mission is to invest in and develop capabilities that advance the technical superiority of the U.S. military to counter new and emerging threats. The overall FY 2017 base budget S&T funding request for the Army, Navy, Air Force, and Defense Agencies is approximately \$12.5 billion, which is 2.4 percent of the Department's \$523.9 billion base budget. The FY 2017 request is slightly lower than the FY 2016 enacted level of \$13.0 billion for continued S&T focus on the rebalance of forces from Iraq and Afghanistan to the Asia Pacific region, and towards promising technologies to counter other nations' development of anti-access/area-denial capabilities.

Highlights of the FY 2017 budget request for S&T include:

- Maintaining a robust Basic Research program of \$2.1 billion
- Continuing the implementation of the Defense Innovation Initiative (DII) that will help to identify investments in innovations to sustain and advance DoD's military dominance for the 21st century. Provides \$45 million in support of this initiative for the Defense Innovation Unit–Experimental (DIU-X) facilities (DIU-X East and DIU-X West) and \$40 million for the Department's pilot program, In-Q-Tel;
- Providing \$137.0 million for the continued support of six DoD-led Manufacturing Initiative institutes and provides funding to establish two additional institutes, which will satisfy the DoD requirement for eight institutes in support of the President's National Network for Manufacturing Innovation plan and the National Economic Council's manufacturing goals; and
- Providing \$35.0 million for the Department's Third Offset Strategy that is designed to counter or offset the technological advances of U.S. foes. Additional efforts that have supported or will continue to support this strategy include:
 - Providing \$902.0 million for the Strategic Capabilities Office, which was established to identify, analyze, demonstrate, and transition game-changing applications of existing and near-term technology to shape and counter emerging threats
- Continuing to analyze the Long Range Research and Development Planning Program study, conducted in 2015, to identify high-payoff enabling technology investments that could shape key future U.S. investments

Figure 5-3. Science & Technology Program

Base budget \$ in billions

Program	FY 2016 Request	FY 2016 Enacted*	FY 2017 Request	FY16 Enacted – FY17 Change
Basic Research (6.1)	2.1	2.3	2.1	-0.2
Applied Research (6.2)	4.7	5.0	4.8	-0.2
Adv Tech Dev (6.3)	5.5	5.7	5.6	-0.1
Total S&T	12.3	13.0	12.5	0.5

*Reflects Congressional adds to include \$100 million for Technology Innovation efforts, \$250 million for the Defense Rapid Innovation Fund, and \$204 million in support of Army, Navy, Air Force, Defense Agencies, and university research programs.

6. TAKE CARE OF OUR PEOPLE

The Military — Active, Reserve, and National Guard — and Civilian personnel are the foundation of the Department of Defense and constitute its premier asset. As such, they must have the full support of the Nation and the Department to ensure they successfully accomplish the arduous mission of defending the United States of America 24/7.

The Department's commitment to a generous compensation package for those individuals willing to serve their country voluntarily is evidenced in an examination of the annual budget request and demonstrated by the number of initiatives and programs to support their professional development and their personal and family lives.

Key Initiatives

- Military Compensation
- Blended Retirement System
- Force of the Future
- Managing the Military Health System
- Strengthening Military Families
- Supporting DoD Civilians

Comprising roughly one-third of the DoD budget, military pay and benefits funding is, and will likely always be, the single largest expense category for the Department. Total compensation funding including civilian personnel consumes nearly half of the budget. Therefore, the Department must be vigilant that these requirements do not grow such that they prevent achieving the Department's strategic goals. Specifically, the Department cannot allow its personnel requirements to crowd out investments in the readiness and modernization portions of the budget, which are essential to providing the needed training and equipment for its warriors to carry into combat and accomplish the incredible array of missions undertaken around the globe every day. Balancing resources is particularly important as the Department reshapes the force needed to remain effective in an uncertain future. Providing a robust pay and benefits package is essential and must be sustained to ensure the best warfighters are available to execute the nation's defense strategy. Nevertheless, although adequate compensation is a vital component of readiness and military quality-of-life, it must remain in balance with readiness, capacity, and capabilities needed.

The Department continues to face significant budget challenges from sequestration under the Budget Control Act of 2011 (BCA 2011). Even with the short-term relief from the sequestration funding caps provided under the two Bipartisan Budget Acts (2013 and 2015), the Department's current topline for the base budget has been reduced by approximately \$800 billion over the 10-year sequestration period (FY 2012 through FY 2021) when compared to the FY 2012 President's Budget (PB) Future Years Defense Program (FYDP) topline estimates (pre sequestration). Over the same 10-year period, the estimated savings from military compensation proposals enacted from FY 2012 through FY 2016 along with those proposed in the FY 2017 President's Budget total to just under \$69 billion — less than 9 percent of the \$800 billion reduction.

Figure 6-1 displays a summary of the Department's base budget pay and benefits funding since the War on Terror began, as illustrated by FY 2001 and FY 2012 through FY 2017. Military pay and benefits funding increased from \$99.5 billion in FY 2001 to \$183.8 billion in FY 2012 (an 85 percent increase), remaining roughly one-third (34.6 percent) of the total budget due to a similar increase in the Department's base budget authority. However, Figure 6-1 also demonstrates that the average cost per capita of military personnel increased significantly during this period. This is evident in the size (end strength) and composition of the force.

The FY 2013 through FY 2015 columns clearly reflect the impacts of the Budget Control Act (BCA) of 2011 and the subsequent Bipartisan Budget Act (BBA) of 2013. The nearly \$9 billion decrease in the FY 2013 base budget military pay and benefits funding includes the shift from

Overview – FY 2017 Defense Budget

base to Overseas Contingency Operations (OCO) funding of non-enduring Army and Marine Corps end strength grown to support wars in Iraq and Afghanistan; it also reflects the slowing of medical growth trends experienced across the Nation in recent years and program delays and one-time reductions taken to meet sequestration funding levels. However, even with these reductions, the base budget military pay and benefits funding actually increased as a percentage of the defense budget (34.6 percent to 35.3 percent) due to the size of the overall reduction to the Department's base budget authority.

Military pay and benefits funding in FY 2016 and FY 2017 reflect modest growth achieved through a combination of force structure reductions consistent with the Quadrennial Defense Review strategy, the continuation of historically low medical inflation trends, numerous efficiencies, and policy changes. These efforts have created a trajectory of growth that puts compensation on a more sustainable path. This started in previous budgets and is continued with the proposals included in the FY 2017 budget request. With the FY 2016 and FY 2017 increases in discretionary spending negotiated in the Bipartisan Budget Act (BBA) of 2015, military pay and benefits funding drops to 34.0 percent of the overall DoD budget authority.

Figure 6-1. Pay & Benefits Funding ^{/1}

(Dollars in Billions)

Military Pay & Benefits Funding	FY 2001 Actual	FY 2012 Actual	FY 2013 Actual	FY 2014 Actual	FY 2015 Actual	FY 2016 Enacted	FY 2017 Request
Military Personnel Appropriations ^{/2}	77.3	130.8	126.4	128.7	127.5	128.7	128.9
Medicare-Eligible Retiree Health Care Accruals	0.0	10.7	8.0	7.3	7.0	6.6	6.4
Defense Health Program ^{/3}	13.7	32.3	30.6	32.7	32.7	32.9	33.8
DoD Education Activity ^{/4}	1.5	3.3	3.2	3.6	3.0	3.1	2.9
Family Housing	3.7	1.7	1.5	1.4	1.1	1.3	1.3
Commissary Subsidy	1.0	1.4	1.4	1.3	1.3	1.4	1.2
Other Benefit Programs ^{/5}	2.4	3.7	4.0	3.5	3.4	3.5	3.4
Military Pay & Benefits Funding	99.5	183.8	175.0	178.5	176.0	177.5	177.9
Civilian Pay & Benefits Funding ^{/6}	39.8	69.6	68.4	68.4	69.6	71.8	72.9
Total Pay & Benefits Funding	139.3	253.4	243.5	246.8	245.5	249.3	250.8
DoD Base Budget Authority (BA)	287.4	530.4	495.5	496.3	497.3	521.7	523.9
Mil Pay & Benefits as % of BA	34.6%	34.6%	35.3%	36.0%	35.4%	34.0%	34.0%
Total Pay & Benefits as % of BA	48.5%	47.8%	49.1%	49.7%	49.4%	47.8%	47.9%
End Strength - Active Component ^{/7}	1,385,116	1,399,622	1,329,745	1,314,016	1,314,110	1,301,300	1,281,900
End Strength - Reserve Component ^{/7}	868,534	840,320	834,651	824,378	819,062	811,000	801,200
Civilian FTEs ^{/8}	687,305	800,052	772,741	755,692	756,334	769,365	763,774

^{/1} Base Budget only -- excludes OCO funding.

Numbers may not add due to rounding

^{/2} Includes pay & allowances, PCS move costs, retired pay accruals, unemployment compensation, etc

^{/3} DHP funding includes O&M, RDT&E, and Procurement. It also includes construction costs funded in Military Construction, Defense-Wide

^{/4} DoDEA funding includes all O&M, Procurement, & Military Construction costs

^{/5} Includes Child Care & Youth Programs, Warfighter & Family Programs, MWR, Tuition Assistance and other voluntary education programs.

^{/6} Civilian Pay & Benefits amounts exclude costs in funded in the DHP, DoDEA, Family Housing and Commissary Subsidy programs.

^{/7} Total number of active and reserve component military personnel funded in the Base Budget on September 30. FY 2016 projected E/S.

^{/8} Total Civilian FTEs Direct/Indirect and Foreign Hires

MILITARY COMPENSATION – BACKGROUND

The Department believes providing competitive pay and benefits is a necessity to attract and retain the highly qualified people needed in today's military. Additionally, it is generally viewed by the public as a national obligation to the small percentage of the population who choose to serve this nation in this capacity. While there is no perfect benchmark or comparison to determine the adequate level of compensation for recruiting and retaining the Force, for more than a decade, the work of the Ninth Quadrennial Review of Military Compensation (9th QRMC) has been the primary measuring stick and justification for many improvements that have occurred in military pay. In the final report, the 9th QRMC asserted that:

Military and civilian pay comparability is critical to the success of the All-Volunteer Force. Military pay must be set at a level that takes into account the special demands associated with military life and should be set above average pay in the private sector. Pay at around the 70th percentile of comparably educated civilians has been necessary to enable the military to recruit and retain the quantity and quality of personnel it requires.

In the late 1990s, even though the trajectory of military compensation was slightly upward, it had sunk to an unsatisfactory level relative to the rest of the working population. The 9th QRMC's analysis noted that in 2000, regular military compensation (RMC) (defined as basic pay, housing and subsistence allowances, and the Federal tax advantage associated with these tax-free allowances) for mid-grade enlisted personnel (E5 – E7s) and mid-grade officers (O4s) only placed in the 50th and 58th percentiles, respectively, compared to similarly educated and experienced workers in the United States. To address this and with the help of the Congress, substantial targeted and overall increases to the basic pay table were enacted, well above the level of growth in private industry wages and salaries as measured by the Employment Cost Index (ECI).

In addition to increasing basic pay, during the same period the Department also began increasing housing allowance rates to bring them in line with actual rental market housing costs across the country and to reduce members' out-of-pocket housing costs. Prior to this initiative, a military member's housing allowance covered only about 80 percent of their full housing costs, leaving an out-of-pocket cost of up to 20 percent. By 2005, housing allowance rates were increased enough so that the median out-of-pocket "off-base" housing cost was completely eliminated for members by pay grade, location, and dependency status. As a further quality-of-life initiative, the Military Services also entered into numerous public-private ventures (PPVs) designed to eliminate inadequate government housing by leveraging private sector financing, expertise, and innovation to provide necessary housing faster and more efficiently than traditional Military Construction processes would allow. The PPV process significantly increased the Department's Basic Allowance for Housing (BAH) program costs due to an increased number of military personnel receiving a housing allowance, but it quickly enhanced the quality-of-life for members and their families through revitalized family housing in many military locations.

By the late 2000's, the increased trajectory of compensation designed to close the gap with the private sector had overshot the mark – understandably so during a decade of war. By 2009 and as a direct result of these improvements, the 11th QRMC reported in June 2012 that average officer and enlisted RMC had climbed to the 83rd and 90th percentile of comparable civilian pay, respectively. It should be noted that while RMC is the foundation, it is by no means the totality of military pay and benefits available to members, a summary of which is provided in Figure 6-2.

Figure 6-2. Military Pay and Benefits Summary

- The foundation of military pay is Regular Military Compensation (RMC). Every member receives the following pay or in-kind entitlement:
 - Basic Pay
 - Basic Allowance for Housing (BAH) with the advantage of being tax-free.
 - Basic Allowance for Subsistence (BAS) with the advantage of being tax-free.
- Members may also receive a series of other allowances to offset the costs they incur because of official travel and relocation, family separation, uniform replacement, and the greater than normal living expenses associated with assignments to high-cost locations.
- Every member receives:
 - 30-days paid vacation annually;
 - Free health, dental, and vision care; and automatic survivor coverage in event of death on active duty. For members on active duty, free health care is also available for their dependents.
- Members who qualify, may receive in addition to the above universal benefits, additional compensation in the form of Special and Incentive (S&I) pays, which are used to target specific occupations, specialties, and segments of the force to:
 - Attract and retain members in certain occupations or specific skills (e.g., enlistment and reenlistment bonuses, critical skills retention bonuses, medical special pays)
 - Motivate attainment of specific skills (e.g., language proficiency pay, dive pay)
 - Recognize hardships, danger, or arduous duty (e.g., hardship duty pay, parachute duty pay, imminent danger pay, firefighting crew member pay)
 - Incentivize hard to fill assignments or those of special responsibility (e.g., assignment incentive pay, special duty assignment pay).
- Members, as well as their dependents, are offered many other non-monetary benefits such as:
 - Subsidized child care
 - Subsidized life insurance
 - Education and tuition assistance
 - Child, youth, and family support programs
 - Discounted retail shopping (Commissary and Exchange)
 - Spiritual health and support
 - Access to a wide range of welfare and recreation offerings (e.g., club, golf, pool, other sports and recreation facilities, commercial discount tickets, internet cafes)
- Members who qualify receive a retirement:
 - Lifetime defined benefit after 20 years of service
 - Lifetime defined benefit upon occurrence of significant disability
 - Most of the same non-monetary benefits as while serving
 - Subsidized health care for self and family
 - Subsidized survivor protection

MILITARY COMPENSATION CHANGES – TO-DATE

Against this backdrop of a healthy and competitive military compensation package, the Department has done a significant amount of work to explore how it can balance the rate of growth in military pay, benefit costs, and individual compensation incentives in a way that is both responsible and fair. The Department has submitted numerous proposals in recent years to do just that, and some portions of which have been accepted and acted upon by the Congress. Authorized adjustments include:

- **FY 2012**
 - Allowed a modest increase in TRICARE Prime enrollment fees (\$5 per month per retiree family plan) and indexed the fees to the annual retiree cost-of-living (COLA) increase
 - Required retirees in the Uniformed Services Family Health Plans (USFHP) to transition to the TRICARE-for-Life (TFL) plan upon becoming Medicare-eligible like all other military retirees

Overview – FY 2017 Defense Budget

- Permitted small increase in pharmacy co-pays
- **FY 2013**
 - Authorized some increases in pharmacy co-pays structured to provide incentives to use generic drugs and the lower cost mail order program over retail pharmacies
- **FY 2014**
 - Accepted an alternative basic pay raise of 1.0 percent vice the 1.8 percent increase equal to the Employment Cost Index (ECI)
- **FY 2015**
 - Accepted an alternative basic pay raise of 1.0 percent vice the 1.8 percent increase equal to the ECI
 - Approved General Officer/Flag Officer (GO/FO) pay freeze for FY 2015
 - Authorized the monthly Basic Allowance for Housing (BAH) rates to be set at 99 percent (vs. 100 percent) of the median rental housing costs
 - Allowed a \$3 increase to retail and mail order pharmacy co-pays and required refills for maintenance drug prescriptions (e.g., cholesterol, blood pressure) to be filled through lower cost mail order or Military Treatment Facility (MTF) pharmacies
- **FY 2016**
 - Accepted an alternative basic pay raise of 1.3 percent vice the 2.3 percent increase equal to the ECI
 - Authorized monthly BAH rates to be set at 95 percent (vs. 99 percent) of the median rental housing costs; phased in 1.0 percent increments per year over 4 years
 - Authorized additional pharmacy co-pay increases in FY 2016
 - Allowed change to policy on second destination transportation for fresh fruit and vegetable supplies for Asia-Pacific commissaries

The Department also has taken other actions to improve efficiencies and to reduce the overall costs for health care. For instance, with the support of Congress, the Department championed changes in law (known as Federal Ceiling Price (FCP)) that required pharmaceutical manufacturers to provide discounts for drugs for TRICARE beneficiaries through retail network pharmacies. As a result, the FCP discounts for drugs are at least 24 percent less than the average manufacturer's price for its non-Federal customers. To further reduce costs, the Department also changed the way it buys medical products by leveraging the bulk buying power of the military health system (MHS). Additional examples are provided in the *Managing the Military Health System* section of this chapter.

These have been important steps in controlling costs. However, given the long-term fiscal realities faced within defense budget funding levels, the Department must continue to explore proposals that promote balanced growth in pay and benefits funding levels.

MILITARY COMPENSATION PROPOSALS – GOING FORWARD

Figure 6-3 displays the estimated savings from the military compensation proposals included in the FY 2017 budget request. These proposals decrease military pay and benefits funding by \$0.5 billion in FY 2017 and \$11.0 billion through FY 2021.

- Basic Pay Raise** — The FY 2017 President's budget proposes a 1.6 percent increase in military basic pay. This is less than the 2.1 percent increase under the formula in current law, which calls for a military pay raise to equal the annual increase in the wages and salaries of private industry employees as measured by ECI. The FY 2017 proposed increase of 1.6 percent is 0.3 percent above the FY 2016 military pay increase of 1.3 percent.

Figure 6-3. FY 2017 PB Military Compensation Proposals
(Dollars in billions)

Proposals	FY 2017 Savings	FY17 – FY21 Savings
FY 2017 Pay Raise of 1.6% (vice 2.1%)	0.3	2.2
TRICARE Modernization Plan	-0.1*	3.5
Pharmacy Co-Pay Adjustments	0.3	2.0
TRICARE-for-Life Enrollment Fee	0.3	1.4
Blended Retirement Amendment	-0.4*	1.9
Total Military Compensation Proposal Savings	0.5	11.0

*Costs

Numbers may not add due to rounding

- TRICARE Modernization Plan** — As detailed in the *Managing the Military Health System* section of this chapter, the FY 2017 budget health benefit reform proposal leverages the FY 2016 proposal seeking to balance the needs of beneficiaries with requirements to maintain military medical readiness. In addition to adding choice for beneficiaries, encouraging the use of military treatment facilities, and modernizing health care cost sharing, the FY 2017 proposal pairs these changes with institutional reforms that are designed to provide greater value and address beneficiary concerns including — access to care that meets the beneficiaries' needs; first call resolution and a greatly improved referral process to improve response times and reduce administrative burdens; and seamless mobility as military members move around the globe.
- Implement Enrollment Fee for New Tricare-for-Life Beneficiaries and Increase Pharmacy Co-Pays** — In conjunction with the TRICARE Plan changes, the Department again seeks to adjust pharmacy co-pay structures and *establish a modest annual enrollment fee for the TRICARE-for-Life* coverage for Medicare-eligible retirees.
- Blended Retirement System** — As detailed in the next section, the Department seeks to amend certain aspects of the new retirement system in order to ensure that, when the new system goes into effect, it meets the needs of the Military Departments and service members today and in the future.

BLENDED RETIREMENT SYSTEM

The National Defense Authorization Act for Fiscal Year 2016 (NDAA) enacted substantial changes to the current military retirement system. For decades, military members have had to serve 20 years before becoming eligible for any retirement benefits, and since roughly 80 percent of Service-members depart before 20 years, most leave without any retirement benefit, which constitutes a disadvantage in comparison to their peers. Under the new system, a member will have the opportunity to achieve a retirement that is the equivalent of or better than retirement under the current system.

Overview – FY 2017 Defense Budget

The current military retirement system consists entirely of a defined retired pay benefit, and the member's retired pay is based upon a formula of 2.5 percent times the number of years served times the average of the member's highest 36 months of basic pay. The new retirement system is a blend of several components, which include:

- a defined retired pay benefit using a 2.0 percent per year multiplier in lieu of 2.5 percent;
- an automatic 1 percent government contribution to the member's account with the Thrift Savings Plan (TSP) after the member serves 60 days;
- government matching contributions to the member's TSP account using the same matching plan as is used for Federal government civilians under the Federal Employee Retirement System; and
- a bonus (continuation pay) paid to the member at the 12th year of service.

The blended retirement system will include all members who join after January 1, 2018, and those who have less than 12 years of service on December 31, 2017, who elect to opt-in. Currently serving members who have more than 12 years of service and those with less than 12 years of service on December 31, 2017, who do not elect to opt-in, will remain grandfathered under the current retirement system.

The FY 2017 accrual savings reflects the impact of the new blended retirement system based on lower retired pay accrual rates as the defined benefit multiplier is reduced from 2.5 percent to 2.0 percent. The savings realized from the reduced accrual rates provide the necessary funding to support the new defined-contribution component consisting of individual military members' TSP accounts and continuation pays necessary to maintain retention at various career points along the Service force profile. However, since the new blended retirement system is not scheduled to take effect until January 1, 2018, the savings in FY 2017 are solely due to the lower accrual rates and not offset by the costs associated with TSP contributions and continuation pays.

In general, the Department supports the blended retirement system established by the National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2016. However, DoD is proposing some modifications now to ensure that, when the new system goes into effect, it best meets the retention needs of the Services and our men and women in uniform.

- The Department seeks flexibility in the application of continuation pays in order to shape the force vice the NDAA, which provides a minimum continuation payment to all members at 12 years-of-service (YOS)
- The Department seeks to increase TSP matching to 5 percent for a total contribution of 6 percent. The NDAA provides a 1 percent automatic TSP contribution to the Service member and up to 4 percent in TSP matching contributions for a total of 5 percent
- The Department seeks to amend the start date for matching service member TSP contributions to the first day of the fifth YOS generally aligning the start date with a service member's second enlistment. The NDAA begins matching the first day of the third YOS
- The Department seeks to extend TSP matching contributions until the member's retirement, similar to civilians covered by the Federal Employees Retirement System, while the NDAA ceases TSP matching contributions at 26 YOS.

FORCE OF THE FUTURE

The Department is evaluating a series of comprehensive reform initiatives to improve recruiting and retention, focus on talent management, and increase permeability between the public and private sectors. The Secretary of Defense announced the first tranche of Force of the Future reforms in a speech at George Washington University on November 18, 2015, where he highlighted the following 12 initiatives focused on permeability to new people and ideas, recruitment, and retention.

- Improving and enhancing college internship programs
- Establishing the Defense Digital Service
- Launching an Entrepreneur-in-Residence Program
- Designating a Chief Recruiting Officer
- Expanding the Secretary of Defense Corporate Fellows Program
- Pursuing legislation to make the Career Intermision Program permanent and increase the size of the program
- Continuing to refine the Blended Retirement System approved in the FY 2016 NDAA
- Piloting a web-based Talent Management System
- Establishing an Office of People Analytics
- Implementing Service member exit surveys
- Commissioning a study to better understand the factors affecting poor recruit outcomes
- Implementing semiannual diversity briefings to senior leaders

Secretary Carter announced a second tranche of reforms on January 28, 2016, focused on improving the quality of life of military parents. This second tranche is intended to allow Service members to better balance commitments they make to serve in uniform and start and support a family. Initiatives include --

- Establishing a DoD-wide standard of 12 weeks paid maternity leave (up from 6 weeks)
- Seeking legislation to expand paternity leave from 10 to 14 days
- Seeking legislation to expand adoption leave for military to military marriages
- Extending Childcare Development Center (CDC) operating hours
- Modifying or establishing about 3,600 Mothers' rooms across DoD installations
- Conducting long-range strategic planning and assessments for childcare options to improve access and usability
- Pursuing an amendment to existing authorities to permit Service members to remain at a duty station of choice in certain instances where it is in the best interests of the family
- Implementing a pilot program to provide egg and sperm cryopreservation services to active duty Service members

The Department anticipates final decisions on the remaining initiatives in the coming months.

- The reforms captured in the Force of the Future initiative represent an investment in maintaining the strongest and most agile fighting force the world has ever known. The U.S. military represents the Department's best competitive advantage in warfare and the Force of the Future initiative examines how the Department can better attract and retain top talent.

Overview – FY 2017 Defense Budget

- The proposed reforms represent a comprehensive overhaul of the military and civilian personnel systems; many ideas will require changes to statute that will be submitted as part of the FY 2017 President's Budget (PB) submission. The DoD looks forward to working with Congress to institute meaningful reform for the Department.
- There is a broad array of topics under consideration that range from the complex (e.g., Defense Officer Personnel Management [DOPMA]) reform to the simple (e.g., increasing inter-agency broadening opportunities for DoD civilians); all of them are designed to increasingly reward top performers, improve quality of life for DoD employees and their families, and optimally manage talent within the Department's ranks.
- All of the costs are being taken from existing DoD resources and additional unidentified savings may be garnered as the Department becomes more efficient as a result of better talent management.

MANAGING THE MILITARY HEALTH SYSTEM

The FY 2017 budget request includes \$48.8 billion for the DoD Unified Medical Budget to support the Military Health System (MHS). The MHS currently has 9.4 million eligible beneficiaries, which includes active military members and their families, military retirees and their families, dependent survivors, and certain eligible Reserve Component members and their families.

Strategic Construct

The MHS is a federated healthcare system responsible for supporting the health needs of the U.S. military and eligible beneficiaries around the world. The MHS consists of the Office of the Assistant Secretary of Defense for Health Affairs (ASD(HA)), the Military Medical Departments (Services), and the Defense Health Agency (DHA). The system supports operational medicine (including combat casualty care, disaster relief, global health engagement, and humanitarian assistance) and provides health services in a global network of military hospitals and clinics. It also purchases more than 65 percent of the total care provided for beneficiaries through tailored contracts. Delivery of the TRICARE health benefit utilizing both military treatment facilities and purchased health services is a shared responsibility executed by the Services and the DHA. The benefit is delivered to several distinct categories of beneficiaries, such as active duty military personnel, families of active duty personnel, reservists, and military retirees and their family members.

Figure 6-4. Military Health Care Funding¹
(Dollars in Billions)

Program	FY 2017 Request
Defense Health (DHP)	33.5
Military Personnel ²	8.6
Military Construction ²	0.3
Health Care Accrual ³	6.4
Unified Medical Budget	48.8
Treasury Receipts for Current Medicare-Eligible Retirees ⁴	10.3

Numbers may not add due to rounding

^{1/} Excludes OCO funds and other transfers. The FY 2017 amounts include \$40 million additional DHP costs and \$589 million Health Care Accrual savings from TRICARE benefit proposals.

^{2/} Funded in Military Personnel & Construction accounts.

^{3/} Includes health care accrual contributions into the Medicare-Eligible Retiree Health Care Fund to provide for the future health care costs of personnel currently serving on active duty – and their family members – when they retire.

^{4/} Transfer receipts in the year of execution to support 2.4 million Medicare-eligible retirees and their family members.

Overview – FY 2017 Defense Budget

The primary mission of the MHS is to support the health readiness of the Force. Given its role in supporting both health readiness and routine healthcare, the benefit serves two primary customer groups:

- Combatant commanders who rely on the system to supply a ready medical force and a medically ready force in support of Globally Integrated Operations (GIO), and
- Beneficiaries who rely on the system for safe and effective health services to meet their healthcare needs.

This dual responsibility distinguishes the MHS from civilian healthcare systems and presents both a challenge and an opportunity.

Health Care Costs

Since its inception in 1994, the TRICARE program has expanded the range of benefits provided to beneficiaries, yet the original cost sharing requirements have remained relatively unchanged. Asking beneficiaries to share in the costs of health care requires congressional action. Over the years, Congress permitted small increases in the TRICARE Prime enrollment fees for working age retirees and made some adjustments to retail and mail order pharmacy co-pays. But these changes are not enough to offset the overall projected increase in health care costs in the long-term. For example, when TRICARE was fully implemented in 1996, a working age retiree's family of three who used civilian care contributed on average roughly 27 percent of the total cost of their health care. Today that percentage has dropped to less than 9 percent. While health care costs have doubled or tripled over this time frame, a family's out-of-pocket expenses, including enrollment fees, deductibles and cost shares, have grown by only 30 to 40 percent.

Controlling health care costs are a priority for the Department of Defense (DoD), and DoD does so using two strategies: 1) achieving some savings within the program itself, and 2) requiring beneficiaries to increase their contribution for the health care that they receive. Over the past several years, program efficiencies have been extremely successful in constraining health care costs. Initiatives included implementation of Federal Ceiling Pricing (a discount drug program), the Outpatient Prospective Payment system (a transition to more favorable Medicare rates for private hospitals), Patient-Centered Medical Homes, and the Defense Health Agency's Shared Services (reducing redundancy and improving coordination among the Services), which have resulted in roughly \$3 billion in annual savings. Concurrently, Congress permitted small increases in the TRICARE Prime enrollment fees for working age retirees and made some adjustments to retail and mail order pharmacy co-pays in the FY 2012, FY 2013, FY 2015, and FY 2016 budget and legislative cycles. These congressional actions are projected to save the Department an additional \$2.4 billion annually.

Taken together, the internal savings initiatives and modest congressional fee increases are helpful but are not enough to curb the projected increase in health care costs for the Department. Following several years of historically low health care inflation, National Health Expenditure projections, a product of the Centers for Medicare and Medicaid Services, anticipate a gradual increase in per capita health care costs to roughly 5 percent in coming years. Additionally, the Military Compensation and Retirement Modernization Commission¹ (MCRMC) recently reviewed and recommended changes to the military compensation and retirement systems.² Some of their recommendations were to improve and modernize the MHS, including the TRICARE benefit plan. The current TRICARE Program is largely

¹ Established by the National Defense Authorization Act FY 2013 Pub. L. 112-239, 126 Stat. 1787 (2013).

² Final report issued January 2015.

unchanged from its inception in 1994. In his response to the MCRMC report, the President stated, “this remains a critical issue, and my Administration will work with the Commission and interested Members of Congress in the coming months to develop additional reform proposals for consideration as part of my Fiscal Year 2017 Budget.” From multiple vantage points, including cost and structure, it is clear the DoD must pursue reasonable health benefit reform now as part of a balanced approach given the reduced sequestration level funding for FY 2018 and beyond.

Health Benefit Reform:

The Department has submitted several reform plans since 2005, largely to control health care costs. These plans have generally been met with resistance in Congress and opposition from Military and Veteran Service Organizations (MSO/VSO). This dynamic changed somewhat with the submission of the President’s Budget (PB) 2016 benefit reform proposal that was relatively well received. Some attributes of this proposal that resonated with beneficiaries, members of Congress, and MSO/VSO included greater simplicity and a perceived increase in value that corresponded to a modest cost increase.

The PB 2017 health benefit reform proposal leverages the PB 2016 proposal but makes some important adjustments. Following are the attributes of the PB 2017 proposal.

- A simpler system — provides beneficiaries with two care alternatives and overall less complexity in their health plan. TRICARE Select is an HMO-like (managed) option that is MTF-centric and TRICARE Choice is a PPO-like (unmanaged) option offering greater choice at a modestly higher cost.
- Economically emphasizes TRICARE Select leveraging MTFs as the lowest cost option for care to make full use of Direct Care capacity and also provides needed workload for military providers for readiness training.
- No change for active duty — who would maintain priority access to health care without any cost sharing but would still require authorization for civilian care.
- Copays — will depend on beneficiary category (excluding active duty) and care venue; designed to minimize overutilization of costly care venues. There would be no copays in MTFs to facilitate the effective use of military clinics and hospitals and thereby improve the efficiency of DoD’s fixed facility cost structure. There would be fixed network copays for the TRICARE Choice option without a deductible.
- Participation fee — for retirees (not medically retired), their families, and survivors of retirees (except survivors of those who died on active duty). They would pay an annual participation fee or forfeit coverage for the plan year. There is no participation fee for active duty members or their family members. There is a higher participation fee for those retirees choosing the TRICARE Choice option (\$200 higher).
- Open season enrollment — similar to most commercial plans, participants must enroll for a 1-year period of coverage or lose the opportunity.
- Catastrophic caps — which have not gone up in 10 years would increase slightly but still remain sufficiently low to protect beneficiaries from financial hardship. The participation fee would no longer count towards the cap.
- Medically retired members and their families and survivors of those who died on active duty would be treated the same as Active Duty family members (ADFM), with no participation fee and lower cost shares.

- To ensure equity among ADFMs, the proposal offers all ADFMs a no cost care option regardless of assignment location and zero copays for ADFM emergency room use, including in the network.
- The Department will offer a second payer option with a lower fee for those with other health insurance.
- Fees and copays will be indexed at the National Health Expenditures (NHE) per capita.

Health benefit reform is more than the cost sharing structure of the benefit itself:

Beneficiaries do not distinguish TRICARE as separate and distinct from the Direct Care System. Instead, they see a continuum of health care services and support. Beneficiaries are concerned about access to timely medical care, particularly for those with exceptional medical needs. In addition, they argue for a reduction in the administrative burdens associated with today's integrated military health system, in keeping with a contemporary approach to health care coverage. They also value choice in health care.

Simply revising the cost sharing structure of TRICARE will not meet beneficiaries' concerns or resolve access to care issues. Instead, the Department must commit to institutional health care reform and implement targeted solutions to solve the variety of issues facing its beneficiaries. The Department's own review, the MHS Review on Quality, Access and Safety, documented many opportunities to improve performance.

The Department needs to pair institutional reforms with a benefit reform package offering real value to the beneficiary. Following are attributes that most observers agree are desirable in a military health benefit package:

- Simplicity, choice, and value for the beneficiary;
- Access to care that meets the beneficiaries' needs; first call resolution and a greatly improved referral process to improve response times and reduce administrative burdens; and seamless mobility as our beneficiaries move around the globe;
- Special consideration of children's needs;
- Emphasis on utilizing the MTF direct care system to maximize capacity and ensure military providers have access to patients/complexity of care for readiness skills;
- Alternate option that offers greater choice but still remains a good value;
- Participation fees and copays that are affordable, maximize use of the direct care system, and tend to direct care to the lowest cost venue of appropriate care ; and
- Economically structured to maintain a reasonable balance between what the beneficiary pays and what the government pays.

The DoD offers a comprehensive health benefit at a significantly lower cost than most other employer sponsored health benefits plans. Even after the proposed changes, TRICARE will remain one of the best health benefits in the United States, with lower out-of-pocket costs compared to other employers. The scope of benefits is not changing, and the Department will continue to invest in those programs and services, like medical readiness and support to wounded warriors and their families, that are critical to sustaining a strong Military Health System and the All-Volunteer Force.

Overview – FY 2017 Defense Budget

FIGURE 6-5. TRICARE PROPOSAL TABLES

Table 1 – Proposed TRICARE Health Plan Participation Fee Rates (Plan Year 2018)

Proposed TRICARE Health Plan Participation Fee (inflated annually by National Health Expenditures (NHE) per capita percentage)	
Non-Medicare eligible beneficiary	TRICARE Select: \$350 individual/ \$700 family TRICARE Choice: \$450 individual/ \$900 family
Medicare eligible beneficiary (TRICARE for Life)	See Table 7

Note 1. Retirees (not medically retired), their families, and survivors of retirees.

Table 2 – Outpatient Cost Sharing for the Proposed TRICARE Health Plan effective January 1, 2018

Services	TRICARE Network and Military Treatment Facility (MTF)				Out-of-Network	
	Active Duty Family Members		Retirees and Family		AD Family Members	Retirees and Family
	TRICARE SELECT ^c	TRICARE CHOICE	TRICARE SELECT ^c	TRICARE CHOICE		
Clinical preventive services ^a	\$0	\$0	\$0	\$0	\$0	\$0
Primary care visit	\$0 MTF \$0 network referral	\$0 MTF \$15 network	\$0 MTF \$20 network referral	\$0 MTF \$25 network	20% ^b	25% ^b
Specialty care visit (including PT, OT, speech)	\$0 MTF \$0 network referral	\$0 MTF \$25 network	\$0 MTF \$30 network referral	\$0 MTF \$35 network	20% ^b	25% ^b
Urgent care center	\$0 MTF visit \$0 network referral	\$0/0/0 MTF \$25 network	\$0 MTF visit \$30 network referral	\$0 MTF \$35 network	20% ^b	25% ^b
Emergency department – emergency care	\$0 MTF visit \$0 network	\$0/0/0 MTF \$50 network	\$0 MTF visit \$75 network	\$0 MTF \$90 network	20% ^b	25% ^b
Ambulance regardless of destination (MTF or network)	\$0 trip	\$15 trip	\$20 trip	\$25 trip	20% ^b	25% ^b
DME, prosthetics, orthotics, & supplies	\$0 MTF \$0 network referral	10% of negotiated network fee	20% of MTF cost or network negotiated fee	20% of MTF cost or network negotiated fee	20% ^b	25% ^b
Ambulatory surgery	\$0 MTF \$0 network referral	\$0 MTF \$50 network	\$0 MTF \$100 network referral	\$50 MTF \$100 network	20% ^b	25% ^b

a. No cost for clinical preventive services as selected by the Affordable Care Act

b. Percentage of TRICARE maximum allowable charge after deductible is met

c. If a TRICARE Select beneficiary obtains care without a referral, Point of Service charges will apply: 50% of the allowed charge after the \$300 individual/\$600 family deductible is met.

Note: PT – physical therapy; OT – occupational therapy; DME – durable medical equipment.

Overview – FY 2017 Defense Budget

Table 3 – Inpatient Cost Sharing for the Proposed TRICARE Health Plan effective January 1, 2018

Services	TRICARE Network and Military Treatment Facility				Out-of-Network	
	Active Duty Family Members		Retirees and Family		Active Duty Family Members	Retirees and Family
	TRICARE SELECT	TRICARE CHOICE	TRICARE SELECT	TRICARE CHOICE		
Hospitalization	\$0 MTF \$0 network referred	\$0 MTF per day \$80 per admission network	\$0 MTF \$200 per admission network referred	\$0 MTF \$250 network per admission	20% ^a	25% ^a
Inpatient skilled nursing / rehabilitation ^b	\$0 network referred	\$25 network per day	\$25 per day network referred	\$25 per day	20% ^a	\$250 per day or 20% ^a of billed charges whichever is less,

a. Percentage of TRICARE maximum allowable charge after deductible is met

b. Inpatient skilled nursing / rehabilitation is generally not offered in MTFs for anyone other than military members.

Table 4 – Deductible and Catastrophic Cap for the Proposed TRICARE Health Plan effective January 1, 2018

General Deductible (out-of-network care)	
E1–E4 active duty family	\$100 individual/\$200 family
All other families	\$300 individual/\$600 family
Catastrophic Cap (per fiscal year)	
Active duty family	\$1,500
Retiree Family	\$4,000

^a Point of Service (POS) fees do not apply to the Catastrophic Cap

Table 5 – Pharmacy Co-Pays effective January 1, 2017

(Amounts in whole dollars)	FY 15	FY 16*	FY 17	FY 18	FY 19	FY 20	FY 21	FY 22	FY 23	FY 24	FY 25	FY 26
Retail Rx (1 month fill)												
Generic	8	10	10	10	11	11	11	11	12	13	14	14
Brand	20	24	28	30	32	34	36	38	40	42	45	46
Non-Formulary	44	Available only on a limited basis										
Mail-Order Rx (3 month fill)												
Generic	0	0	0	0	0	11	11	11	12	13	14	14
Brand	16	20	28	30	32	34	36	38	40	43	45	46
Non-Formulary	46	49	54	58	62	66	70	75	80	85	90	92

Military Treatment Facilities

No change — still \$0 co-pay

*Increases for FY 2016 authorized by the National Defense Authorization Act for FY 2016

Overview – FY 2017 Defense Budget

Table 6 – Cost-Sharing Impact on Beneficiary Families (CY 2018)

		Current TRICARE Triple Option	Proposed TRICARE Health Plan
Active Duty Family ^a (3 members not including service member)			
	DoD cost	\$ 13,776	\$ 13,744
	Family cost	\$ 189	\$ 219
	Total	\$ 13,965	\$ 13,963
	% borne by family	1.4%	1.6%
Non-Medicare eligible Retiree Family ^b (3 members, all under age 65)			
	DoD cost	\$ 15,623	\$ 15,042
	Family cost	\$ 1,360	\$ 1,768
	Total	\$ 16,982	\$ 16,809
	% borne by family	8.0%	10.5%

Note 1. The analysis assumes an average mix of MTF and civilian care within each beneficiary category, and a weighted average of Prime and Non-Prime users for the current TRICARE triple option (or former Prime and NonPrime users), for the proposed TRICARE health plan. For those using all civilian care, the percent borne by the family is slightly higher.

Note 2. The annual employer health benefits survey published by Kaiser Family Foundation (KFF)/Health Research & Educational Trust (HRET) offers a useful benchmark for comparison (<http://kff.org/health-costs/>).

a. Active duty family cost-sharing structure also applies to transitional survivors, TRICARE Young Adult beneficiaries with an active duty sponsor, the Transitional Assistance Management Program, and TRICARE Reserve Select.

b. Retiree cost-sharing structure also applies to survivors, TRICARE Young Adult beneficiaries with a retired sponsor, and TRICARE Retired Reserve.

Table 7 – TRICARE-for-Life Annual Family (Two Individuals) Enrollment Fees*

Retired Pay	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Percentage of Gross Retired Pay (GRP)	N/A	0.50%	1.00%	1.50%	2.00%	2.00%
Ceiling	\$0	\$150	\$300	\$450	\$600	\$632
Flag Officer Ceiling	\$0	\$200	\$400	\$600	\$800	\$842

* Individual fees are 50 percent of family fees (e.g., 1 percent of GRP in FY 2020 and after). Ceilings indexed to retiree National Health Expenditures (NHE) per capita after FY 2020

STRENGTHENING MILITARY FAMILIES

The Department will keep faith with military members and their families, who have borne the burden of a decade of war, by providing military family assistance programs including child care, non-medical counseling, and Morale, Welfare, and Recreation (MWR) programs. The Department recognizes the demands that continue to be placed on the All-Volunteer Force and their families and remains committed to providing assistance. The Military Departments plan to continue the vital family assistance to military members and their families on more than 300 installations worldwide.

The major initiatives to improve the quality-of-life of military members and their families are designed to mitigate the demands of military life — especially the challenges of deployments

and frequent relocations. The Spouse Education and Career Opportunities program supports spouse educational and career development, recognizing that spouses' lives are disrupted when they relocate every few years with their service member. Military OneSource, a 24/7 information and assistance line, links military members and their families to a community-based non-medical counselor for up to 12 free sessions per issue (no limits on financial issues) to address relationship issues or other stressful situations before they escalate. The MWR program provides much needed recreational and fitness resources for all members of the family to promote overall well-being. These are just a few examples of the web of support designed to ensure that military members can confidently attend to the larger Defense mission, knowing that their family is able to thrive.

The FY 2017 base budget includes \$7.6 billion (Figure 6-6) for military family support programs. The \$0.5 billion decrease from the FY 2016 enacted funding level for military family support programs is driven by a school construction deferral and the lower Commissary operating support request.

Figure 6-6 displays a summary of the Department's FY 2015 — FY 2017 base budget for these programs. Key programs are:

- **Child Care and Youth Programs:** Includes funding for child care providers, who serve over 200,000 children, and child and youth development programs, which serve over 500,000 children.
- **Morale, Welfare, and Recreation programs:** Includes funding for mission-sustaining programs such as fitness centers, libraries, and single service member programs; voluntary education; tuition assistance; and recreation programs such as outdoor recreation and auto skills centers.
- **Warfighter and Family Services:** Includes funding for family support centers, Armed Forces Exchanges, transition assistance, and non-medical counseling support services for Active Duty, National Guard, and Reserve members and their families.
- **Commissary:** Includes funding for the Defense Commissary Agency to operate 240 commissary stores on military installations worldwide, employing a workforce of over 14,000 civilian full-time equivalents.
- **Department of Defense Education Activity (DoDEA) Schools:** Includes funding to support the education of 80,527 students in 177 schools (52,284 students in 115 schools in 12 countries and 28,243 students in 62 schools in 7 states, Puerto Rico, and Guam).
- **Spouse Employment program:** Provides funding for the Spouse Employment and Career Opportunities Program, which includes funding tuition assistance for eligible military spouses through the My Career Advancement Accounts program, employment counseling, and assistance to all military spouses to obtain employment and career opportunities through the Military Spouse Employment Partnership.

Overview – FY 2017 Defense Budget

Figure 6-6. Military Family Support Programs

(Dollars in Billions, Base Budget only)

Program	FY 2015 Actual	FY 2016 Enacted	FY 2017 Request
Child Care and Youth Programs	1.0	1.2	1.3
Morale, Welfare and Recreation	1.4	1.5	1.5
Warfighter and Family Services	1.5	1.6	1.5
Commissary	1.3	1.4	1.2
DoDEA Schools	2.4	2.3	2.1
Military Spouse Employment	0.1	0.1	0.1
Total	7.7	8.2	7.7

As the Department continues to reshape its forces for current and future missions, it is committed to sustaining a balanced portfolio of family assistance programs that are fiscally sustainable and continue to promote service member and family readiness. The overall funding for family assistance programs was determined strategically, based on the number of military members and families served, but without degradation in the quality of the programs provided.

SUPPORTING DOD CIVILIANS

The FY 2017 budget request supports a properly sized and highly capable civilian workforce that is aligned to mission and workload, shaped to reflect changes to the Department's reduced force structure. Civilian personnel perform critical functions in intelligence, equipment maintenance, medical care, family support, base operating services, and other activities that directly support the military forces and readiness. While maintaining training and readiness levels to support the All-Volunteer Force and providing services to their families, the civilian workforce recognizes evolving critical demands such as emerging cyber technologies and threats, and guards against an erosion of organic skills and an overreliance on contracted services.

Civilian workforce reductions in the FY 2017 budget reflect an analytically based workforce-to-workload review designed to preserve mission essential skills and capabilities. The FY 2017 budget builds on previous efforts to reduce the civilian workforce by further reducing the Major DoD Headquarters Activities (MHA) by up to 25 percent but recognizes that certain functions that must grow. The Department will comply with legislative requirements outlined in section 346 of the National Defense Authorization Act (NDAA) for the FY 2016, leveraging opportunities to reshape the civilian workforce through realignments and workload reductions consistent with overall Department strategies and with due consideration of the growing number of statutory force-management and workload sourcing mandates.

The Department estimates the number of civilian Full-Time Equivalents (excluding Classified Activities, Cemeteries, and Foreign National Indirect Hire (FNIH) FTEs) will decline 0.7 percent from 738 thousand in FY 2016 to 733 thousand in FY 2017. The Military Departments and Defense Agencies will begin to shape the workforce to reflect the changing post-OCO needs and a declining military force. The need for some skills, such as cyber, ship maintenance, disability evaluation, sexual-assault prevention, and auditing, will increase. Other skillsets directly related to the war, such as skills supporting depot maintenance and base support for military end strength, will decrease over time. Actions may include early-out incentives and temporary suspension of recruitment actions to allow the Military Departments and Defense

Overview – FY 2017 Defense Budget

Agencies to more fully assess the impact of mission changes, the continuous improvement of business practices, refined process efficiencies, and elimination of unintended redundancies within the workforce.

The civilian workforce continues to be a critical asset across the Department. As the workforce decreases in numbers, the Department remains concerned about the ability to attract and retain a highly qualified civilian workforce after pay freezes from 2011 through 2013 and raises of just 1 percent or slightly more in 2014 and 2015. The Department will continue to support the civilian workforce, including a civilian pay raise of 1.6 percent in the FY 2017 request. Renewed emphasis will be placed on civilian education, training, and leadership development. This FY 2017 request reflects the Department's commitment to finding creative solutions to recruiting, promoting, and retaining the highest caliber of public servants available to serve among our ranks.

Figure 6-7. Civilian FTEs^{1/}

Program	FY 2016 ^{2/} Estimate	FY 2017 ^{2/} Request	Percent Change
Army	189.9	184.8	-2.7%
Navy	190.5	191.9	0.7%
Air Force	166.3	166.3	0.0%
Defense Wide	191.3	189.9	-0.7%
Total DoD	738.1	732.9	-0.7%
U.S. Direct Hires	722.7	717.6	-0.7%
Foreign Direct Hires	15.4	15.3	-0.9%

^{1/} Excludes Classified Activity, Cemetery Expense, and Foreign National Indirect Hire (FNIH) FTEs

^{2/} Includes 674 OCO FTEs in FY 2016 and 619 in FY 2017; excludes 31,629 of Foreign National Indirect Hire (FNIH) FTEs in FY 2016 and 31,487 in FY 2017

7. OVERSEAS CONTINGENCY OPERATIONS (OCO)

SUMMARY

The FY 2017 budget requests \$58.8 billion for overseas contingency operations (OCO) spending, in accordance with the Bipartisan Budget Act (BBA) of 2015. This request focuses on Operation FREEDOM'S SENTINEL (OFS) in Afghanistan, Operation INHERENT RESOLVE (OIR) in Iraq and the Levant, increasing efforts to support European allies and deter aggression, and supporting a partnership-focused approach to counterterrorism. Figure 7.1 displays requested OCO funding by Military Activity.

The request supports the following activities:

- Maintaining a U.S. presence in Afghanistan consistent with the President's drawdown plan;
- Sustaining personnel forward deployed to the Middle East to conduct a range of operations alongside a robust international coalition to degrade and defeat the Islamic State of Iraq and the Levant (ISIL);
- Building the capacity of the Iraqi and Syrian opposition forces to counter ISIL in Iraq and Syria in support of the United States' comprehensive regional strategy;
- Conducting in-country and in-theater support activities, such as intelligence support to military operations;
- Supporting partner nations through a more sustainable approach to counterterrorism; and
- Enhancing U.S. assurance and deterrence activities in Eastern Europe to assure North Atlantic Treaty Organization (NATO) allies and partners and deter aggressive actors in the region.

The FY 2017 OCO budget request remains relatively consistent with the FY 2016 enacted amount of \$58.6 billion, including congressional adds and cancellations of prior year appropriations. The primary drivers of the FY 2017 OCO amount include: (1) the

Continuing the Afghan Transition, Eliminating Terrorist Threats, and Deterring Aggression

- Summary
- Force Level Budget Assumptions
- Overseas Contingency Operations Budget Request
- Iraq Train and Equip Fund
- Syria Train and Equip Fund
- Counterterrorism Partnerships Fund
- European Reassurance Initiative

Figure 7.1 OCO Funding by Activity

(Dollars in Billions)

Operation/Activity	FY 2016 Enacted	FY 2017 Request
Operation FREEDOM'S SENTINEL (OFS) and Related Missions	42.9	41.7
Operation INHERENT RESOLVE (OIR) and Related Missions	5.0	7.5
European Reassurance Initiative (ERI)	0.8	3.4
Counterterrorism Partnerships Fund (CTPF)	1.1	1.0
National Guard and Reserve Equipment/Restore Military Readiness	1.5	--
Subtotal	51.3	53.6
Prior-Year Rescissions ^{1/}	-0.4	--
Bipartisan Budget Act (BBA) of 2015 Compliance ^{2/}	7.7	5.2
Grand Total	58.6	58.8^{3/}

^{1/} From FY 2015 Afghanistan Security Forces Fund (\$400M)

^{2/} FY 2016 Enacted 'BBA Compliance' includes Congressional adds and base budget amounts transferred by the Congress (ISR Improvement Fund \$500M, Ukraine Security Assistance Initiative \$250M, and \$7.0B in transfers and increases)^{3/} Excludes the portion of the congressional base budget fuel adjustment that was applied to OCO (\$893.5M)

Overview – FY 2017 Defense Budget

President's plan to extend the presence of U.S. forces in Afghanistan; (2) intensified operations to counter ISIL; (3) expanded U.S. presence in Eastern Europe; and (4) compliance with the funding caps established by the Bipartisan Budget Act (BBA) of 2015.

FORCE LEVEL BUDGET ASSUMPTIONS

In October 2015, the President approved plans for a future military presence in Afghanistan in support of the Department's dual counterterrorism (CT) and train, advise, and assist mission to the Afghan National Defense and Security Forces (ANDSF). The U.S. will sustain up to 9,800 troops through calendar year 2016 before drawing down to approximately 5,500 troops by January 2017.

In Iraq and the Levant, the U.S. and coalition partners focus on destroying ISIL through active and effective air strikes and enabling local partners on the ground to seize territory from ISIL and deliver it a lasting defeat, without putting U.S. forces on the front lines. The budgeted force levels in Iraq represent the forces associated with the counter-ISIL mission as well as Iraq and Syria train and equip efforts.

Figure 7.2 displays the force levels assumed in the Department's FY 2017 OCO budget, expressed as annual average troop strength. In FY 2017, the average annual troop strength of 6,217 in Afghanistan is consistent with the President's drawdown plan. The average annual troop strength of 3,550 in Iraq is consistent with the President's counter-ISIL mission.

Figure 7.2. U.S. Force Level Assumptions in DoD OCO Budget
(Average Annual Troop Strength)

Force	FY 2015 Actuals	FY 2016 Enacted	FY 2017 Request
Afghanistan (OFS)	10,012	9,737	6,217
Iraq (OIR)	3,180	3,550	3,550
In-Theater Support ¹	55,958	55,831	58,593
In CONUS ² /Other Mobilization	16,020	15,991	13,085
Total Force Levels	85,170	85,108	81,445

¹ IN-Theater support includes support for Afghanistan/Iraq, Combined Joint Task Force (CJTF) HOA / NW Africa CT, and ERI (including approximately 10,500 afloat forces).

² In-CONUS = In the Continental United States

OVERSEAS CONTINGENCY OPERATIONS BUDGET REQUEST

Funding in the FY 2017 OCO budget request is captured by operational support category in Figure 7.3, followed by brief explanations of select activities.

Figure 7.3. OCO Functional/Mission Category Breakout

(Dollars in Billions)

OCO Budget	FY 2016 Enacted	FY 2017 Request
Operations/Force Protection	8.8	8.7
In-Theater Support	14.8	17.0
Joint Improvised-Threat Defeat Fund	0.4	0.3
Afghanistan Security Forces Fund (ASFF)	3.6	3.4
Support for Coalition Forces	1.4	1.4
Iraq Train and Equip Fund (ITEF)	0.7	0.6
Syria Train and Equip Fund (STEF) ¹	--	0.3
Equipment Reset and Readiness	10.1	9.4
Classified Programs	8.1	8.1
Counterterrorism Partnerships Fund (CTPF) ¹	1.1	1.0
European Reassurance Initiative (ERI)	0.8	3.4
National Guard and Reserve Equipment/Military Readiness	1.5	--
Subtotal	51.3	53.6
Prior-Year Cancellation	-0.4	--
Bipartisan Budget Act (BBA) of 2015 Compliance	7.7	5.2
Total	58.6	58.8

¹ In FY 2016, Congress did not establish the STEF account, but did authorize the Syria Train and Equip (ST&E) mission. The Department is likely to leverage CTPF funding for the ST&E mission in FY 2016. Numbers may not add due to rounding

Operations/Force Protection (\$8.7 billion): This category of incremental cost includes the full spectrum of military operations requirements for U.S. personnel operating in Afghanistan, Iraq, and the Levant:

- Personnel special pays and subsistence for deployed forces;
- Personnel pay for mobilized forces;
- Operating tempo (ground vehicles/equipment, combat aviation, Special Operations Forces);
- Communications;
- Pre-deployment training;
- Transportation cost to sustain and support the forces, to include the retrograde of U.S. equipment from Afghanistan;
- Various classes of supplies;
- Deployment and redeployment of combat and support forces;
- Life support and sustainment; and
- Additional body armor and personal protective gear.

In-Theater Support (\$17.0 billion): Funds requested in this category provide for critical combat and other support for personnel in Afghanistan and Iraq that comes from units and forces operating outside Afghanistan and Iraq. This category also includes funding to support other operations conducted outside Afghanistan and Iraq.

The types of cost incurred for in-theater operations are similar to those outlined in the “Operations/Force Protection” category. However, this category also includes incremental costs for afloat and air expeditionary forces, engineers, fire support, and other capabilities located elsewhere that support operations in Afghanistan, Iraq, and other important missions. It also includes support for some activities operating from the United States (such as remote piloted aircraft and reach back intelligence, surveillance, and reconnaissance (ISR) capabilities).

- ***Office of Security Cooperation — Iraq (OSC-I) (\$0.085 billion):*** This program is DoD’s cornerstone for achieving the long-term U.S. goal of building partnership capacity in the Iraqi Security Forces (ISF). The OSC-I conducts the full range of traditional security cooperation activities such as joint exercise planning, combined arms training, conflict resolution, multilateral peace operations, senior level visits, and other forms of bilateral engagement. Additionally, the OSC-I conducts security cooperation activities in support of the ISF to include CT training, institutional training; ministerial and service level advisors; logistic and operations capacity building; intelligence integration; and interagency collaboration. The OSC-I is the critical Defense component of the U.S. Mission Iraq and a foundational element of the long-term strategic partnership with Iraq.
- ***Commander’s Emergency Response Program (CERP) (\$0.005 billion):*** This program provides a vital resource that allows military commanders on the ground in Afghanistan to respond to urgent humanitarian relief and reconstruction needs within their areas of responsibility by carrying out programs that will immediately assist the Afghan people and assist U.S. forces in maintaining security gains, thereby advancing the counterinsurgency mission.

Joint Improvised-Threat Defeat Fund (\$0.4 billion): These funds will be used to understand, develop, procure, and field measures to defeat improvised threats to U.S. forces, closing the gap between the enemy’s innovation cycles and operational capabilities used by the Joint Force. The FY 2017 budget request for the Joint Improvised-Threat Defeat Fund marks the transition of essential enduring capabilities to a permanent organization under the Defense Threat Reduction Agency (DTRA). Includes \$113 million in BBA compliance funding.

Afghanistan Security Forces Fund (ASFF) (\$3.4 billion): This request funds the sustainment, operations, and professionalization of up to 352,000 members of the ANDSF, including 195,000 members of the Afghan National Army (ANA) and 157,000 Afghan National Police (ANP). The request funds the sustainment of the ANA and ANP and supports further development of the capacity of the Afghan Ministries of Defense and Interior to sustain and command and control their forces.

Support for Coalition Forces (\$1.4 billion): Amounts requested finance coalition, friendly forces, and a variety of support requirements for key foreign partners who wish to participate in U.S. military operations but lack financial means. Such support reduces the burden on U.S. forces and is critical to overall mission success.

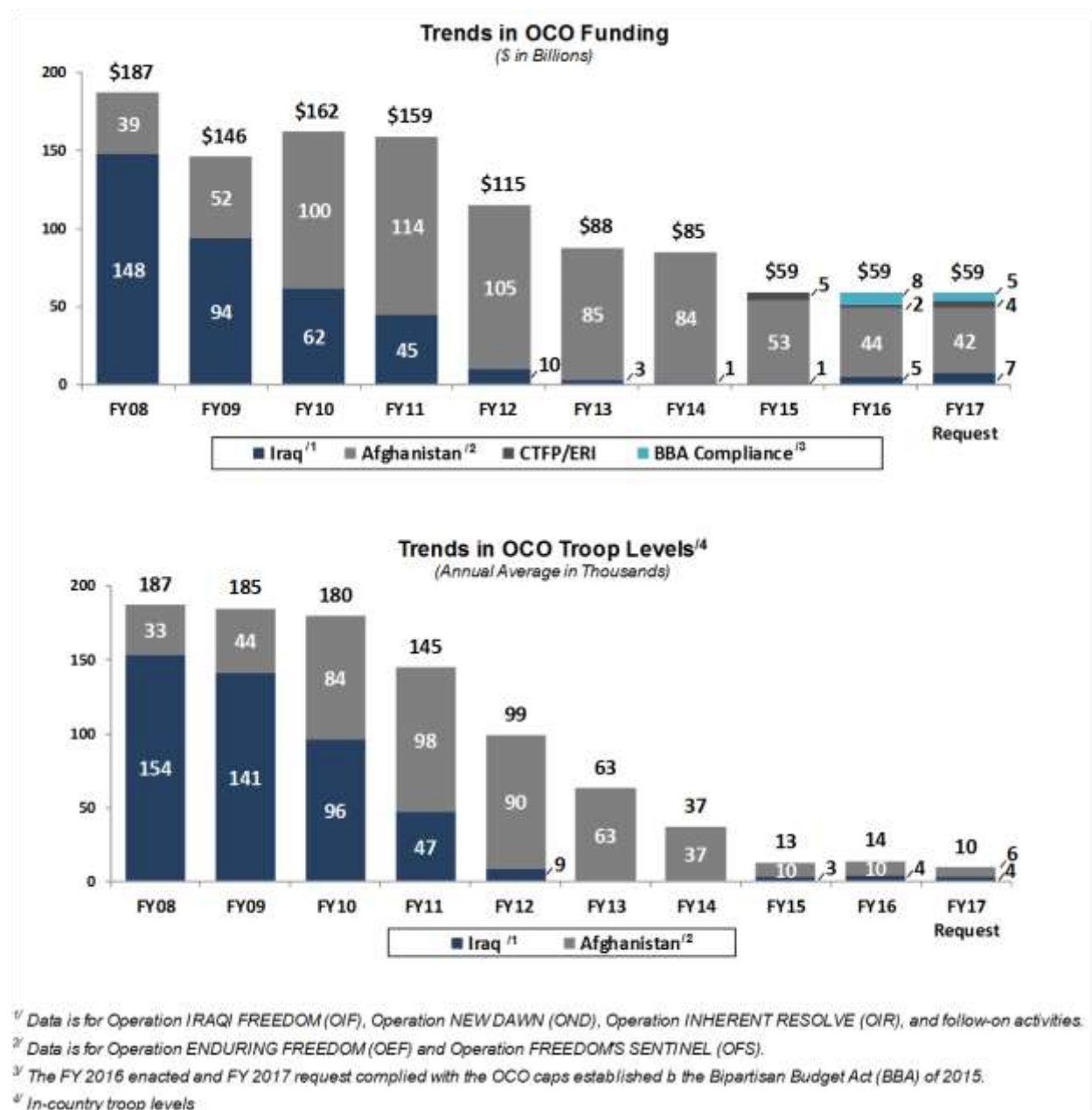
Equipment Reset (\$9.4 billion): The request funds the replenishment, replacement, and repair of equipment and munitions expended, destroyed, damaged, or worn out due to prolonged use in combat operations. The major items that will be repaired or replaced include helicopters, fixed wing aircraft, trucks, other tactical vehicles, Mine-Resistant Ambush Protected (MRAP) vehicles, radios, and various combat support equipment. Munitions that will be

Overview – FY 2017 Defense Budget

replenished include missiles, such as the Laser Maverick, Standoff Precision Guided Munitions (SOPGM), and Hellfire, and ammunition for all the Military Services. Upon returning from war zones, units restore their equipment to a condition that enables them to conduct training exercises, achieve required readiness levels, and prepare for future deployments. As personnel and equipment return from theater to their home stations, the need for equipment reset will continue for several years.

The FY 2017 OCO request for \$58.8 billion is down substantially from requests in recent years, and reflects less than a 1 percent reduction from the FY 2016 enacted OCO level of \$58.6 billion (Figure 7.4).

Figure 7.4. OCO Funding and Troop Level Trends



IRAQ TRAIN AND EQUIP FUND

The continued and evolving nature of the Islamic State of Iraq and Levant (ISIL), also known as Daesh, underscores the importance of training, advising, assisting, and equipping Iraqi Security Forces (ISF). The Iraq Train and Equip Fund (ITEF) enhances the ISF's ability to liberate and secure lost territory, secure borders, protect the population, and further improve the quality of provincial and national defenses.

To build the required capacity and achieve U.S. objectives, U.S. assistance in FY 2017 will focus on: (1) training and equipping additional ISF elements needed to hold liberated areas and establish local security; (2) providing equipment and supplies needed for ongoing counter-ISIL/Daesh operations; and (3) performing maintenance and providing sustainment for equipment vital to the defeat of ISIL/Daesh.

The requested FY 2017 ITEF funding of \$630 million will further the critical work accomplished in FY 2015 and FY 2016 and is a key component of the U.S. counter-ISIL/Daesh strategy. Helping the Government of Iraq to develop a sustainable defense force is essential to ensure lasting security and stability in Iraq.

SYRIA TRAIN AND EQUIP FUND

The Syria Train and Equip Fund (STEF) is a key component of the U.S. Government's strategy to degrade, dismantle, and ultimately defeat the ISIL/Daesh. The absence of a national military or civilian partner in Syria and the disparate nature of the Syrian opposition have constrained progress in the counter-ISIL campaign.

The STEF provides resources to train, equip, and/or sustain appropriately vetted opposition forces engaged in the counter-ISIL/Daesh fight. The train and equip program addresses the immediate need to enable and build the capacity of partners on the ground within Syria to degrade and destroy the ISIL/Daesh threat.

Military operations in the fight against ISIL/Daesh in Syria continue to evolve, increase in scale, and grow in complexity. A flexible train and equip program, resourced through the requested FY 2017 STEF, will enable the Department to provide the equipment and supplies needed to reinforce battlefield successes while continuing to explore opportunities to provide targeted training to vetted opposition forces.

COUNTERTERRORISM PARTNERSHIPS FUND

The FY 2017 request of \$1.0 billion for the Counterterrorism Partnerships Fund (CTPF) will continue the President's initiative to support a more sustainable and partnership-focused approach to counterterrorism in the U.S. Africa Command (USAFRICOM) and U.S. Central Command (USCENTCOM) areas of responsibility. The CTPF allows U.S. forces to be more readily available for other contingency operations, build better relationships with partners, and promote global security in a more cost effective manner. The CTPF will provide direct CT support to partner nations and augment U.S. capability to support partners in CT operations.

The CTPF is set up to permit DoD — consistent with guidance from an interagency process and appropriate notification to Congress — to transfer funds to other accounts for execution.

Overview – FY 2017 Defense Budget

Figure 7.5 CTPF Funding Request
(Dollars in Billions)

	FY 2015 Enacted ^{1/}	FY 2016 Enacted ^{2/}	FY 2017 Request ^{3/}	△ FY16 - FY17	%△ FY16 - FY17
Counterterrorism Partnerships Fund	1.3	1.1	1.0	-0.1	-9.1%
TOTAL	1.3	1.1	1.0	-0.1	-9.1%

^{1/} In FY 2015, \$500 million of the \$1.3 billion for CTPF was allocated for Syria Train and Equip (ST&E)

^{2/} In FY 2016, the Department may use a portion of CTPF funding for authorized (but unfunded) ST&E programs

^{3/} The FY 2017 request excludes funding for ST&E (requested in a separate fund)

EUROPEAN REASSURANCE INITIATIVE

This budget enhances the President's European Reassurance Initiative (ERI), which was originally proposed in Warsaw on June 3, 2014. The FY 2017 budget request of \$3.4 billion for ERI continues efforts started in FY 2015 and FY 2016 to reassure allies of the U.S. commitment to their security and territorial integrity as members of the NATO Alliance. The request provides near-term flexibility and responsiveness to the evolving concerns of U.S. allies and partners in Europe (especially Central and Eastern Europe), and help increase the capability and readiness of U.S. allies and partners. The FY 2017 funding request also supports the expansion of ERI to provide measures for a quick joint response against any threats made by aggressive actors in the region.

Specifically, the request funds enhanced training and exercises, improvements to key infrastructure, and three continuous brigade-sized rotations to train with allies. It also funds the placement of a full set of Army Prepositioned Stocks (APS) in Europe consisting of one Armored Brigade Combat Teams (ABCT), a fires element, a division headquarters, and associated enablers. The request sustains the ABCT European Activity Set (EAS) currently in theater conducting exercises with NATO allies and partners.

The DoD would continue several lines of effort to accomplish the purposes of this initiative, including: (1) increased U.S. military presence in Europe; (2) additional bilateral and multilateral exercises and training with allies and partners; (3) improved infrastructure to allow for greater responsiveness; (4) enhanced prepositioning of U.S. equipment in Europe; and (5) intensified efforts to build partner capacity for newer NATO members and other partners. Funding for ERI is requested in the applicable Component's accounts. Figure 7.6 provides the allocation of ERI by categories.

Figure 7.6 Allocations for European Reassurance Initiative Categories
(Dollars in Millions)

Categories	FY 2015 Enacted	FY 2016 Enacted ^{2/}	FY 2017 Request
Increased Presence	423.1	471.4	1,049.8
Exercises and Training	40.6	108.4	163.1
Improved Infrastructure	196.5	89.1	217.4
Enhanced Prepositioning	136.1	57.8	1,903.9
Building Partner Capacity	13.7	62.6	85.5
ERI Transfer Fund ^{1/}	175.0	--	--
Total	985.0	789.3	3,419.7

^{1/} The Consolidated and Further Continuing Appropriations Act, 2015 (PL 113-235) provided \$175 million in the ERI transfer fund to support the Governments of Ukraine, Estonia, Lithuania, and Latvia.

^{2/} The Consolidated Appropriations Act, 2016 (PL 114-113) provided an additional \$250 million to support the Government of Ukraine [not shown above].

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8. MILITARY DEPARTMENTS

The Military Departments generally use several means to report to the Congress on their activities. Consistent with Title 10 Section 113 (c)(1)(A) each of the Military Departments is providing a summary of their FY 2017 Budget submission for inclusion in the OSD Budget Overview. Additional data are contained in Appendix A, Resource Exhibits.

DEPARTMENT OF THE ARMY OVERVIEW

Introduction

The Army continues to meet the priorities in the National Security Strategy (NSS) and the National Military Strategy (NMS) with a trained and ready Army while transitioning to a smaller fighting force that seeks to increase lethality by balancing capacity, capability, and readiness.

The principle purpose of the Army remains to preserve the nation's freedom by fighting and winning wars. The Army of today, under diminishing resources, faces an increasingly uncertain global security environment. To remain an effective instrument of the nation's military power will require intense planning and difficult decisions. Accordingly, to fulfill the security demands of the nation, in FY 2017, the Army will prioritize readiness, focus investment in key modernization programs, and ensure Soldiers receive the support required to sustain the world's greatest Army. As the Army approaches a total end strength of 980,000 (AC 450,000/ARNG 335,000/USAR 195,000) Soldiers by FY 2018, it must constantly assess threats, operational tempo and associated impacts on the health and viability of the force. The Army must preserve both the capability to respond to unforeseen demands and the capacity to sustain high levels of readiness in the force to meet current global requirements.

In the past year, the Army developed and implemented the Army Operating Concept, "Win in a Complex World," to manage as the Army continues to downsize. The foundation of the Army Operating Concept is the ability to conduct combined arms maneuver. The Army Operating Concept endeavors to build a force, operating alongside many partners, able to respond to multiple adversarial dilemmas while providing commanders synchronizing and integrating options and effects from various domains. The Army Operating Concept envisions an Army that is expeditionary, tailorable, scalable, and prepared to meet the changing challenges of the global environment. The Army Operating Concept sets the foundation upon which leaders can focus the efforts and resources needed to maintain the strategic and operational flexibility to deter and operate in multiple regions simultaneously — in all phases of military operations — to prevent conflict, shape the security environment, and win wars now and in the future.

Nevertheless, fiscal challenges strain the Army's ability to meet NMS requirements and bring into balance readiness, modernization, and end strength. Operating in a fiscally constrained environment adds significant risk to the Army's ability to satisfy its 2014 Quadrennial Defense Review obligations and fulfill its national security requirements. Although the Bipartisan Budget Acts of 2013 (BBA13) and 2015 (BBA15) provided two 2-year windows of fiscal predictability above the sequestration funding levels, funding in the second year of each act has been markedly lower than the initial program. A predictable and consistent fiscal topline is integral to prudent, resourced informed decision-making.

This is a profession built on trust. In holding true to that trust, the nation expects the Army's competence, commitment, and character to reflect the Army values. To that end, the Army is working to reduce and eventually eliminate sexual assault and sexual harassment, which destroys good order and discipline and is contrary to the Army's core values. The Army has increased opportunities for women and is opening all positions based on standards, free from

any gender bias. Finally, programs like Soldier for Life and the Ready and Resilient Campaign are demonstrating the commitment to care for the Soldiers, Civilians, and Families who selflessly sacrifice so much. These programs are combat multipliers critical to Army readiness.

Department of the Army Objectives

The FY 2017 budget request supports the priorities established by the Secretary of the Army (SA) and the Chief of Staff of the Army (CSA). It provides the framework for cultural change and focuses on the future in preparing and sustaining land forces capable of preventing conflict, shaping the strategic environment, and, when called upon, fighting to win decisively. The topical discussions that follow highlight specific details on the strategies that the Army incorporated in its FY 2017 budget request to achieve senior leader priorities and objectives.

Contemporary Security Challenges

The complexity and number of security challenges in the world are intensifying and combatant commanders increasingly need more Army forces to meet these security challenges. Assigned and allocated Army forces provide combatant commanders with the capability to prevent conflict, shape the environment, and when required, fight to win. Increased demand for Army forces means the Army is more globally engaged than ever, with 190,000 Active Component, Army National Guard and U.S. Army Reserve Soldiers on active duty in 140 countries supporting the geographic combatant commanders. Focused regional engagement is necessary for combatant commanders to prevent future conflict by shaping the environment. However, due to reduced force levels, the Army's capacity to simultaneously maintain current commitments and defeat near peer adversaries if required is at risk. The Army's forward presence and stationing builds partner capacity, assures the nation's allies, and deters aggressors. Soldiers are conducting "Train, Advise, and Assist" missions around the world to build partner capacity with allied forces and support host nation partner relations, and to defend DoD personnel and lines of communication.

Adapting to New Realities

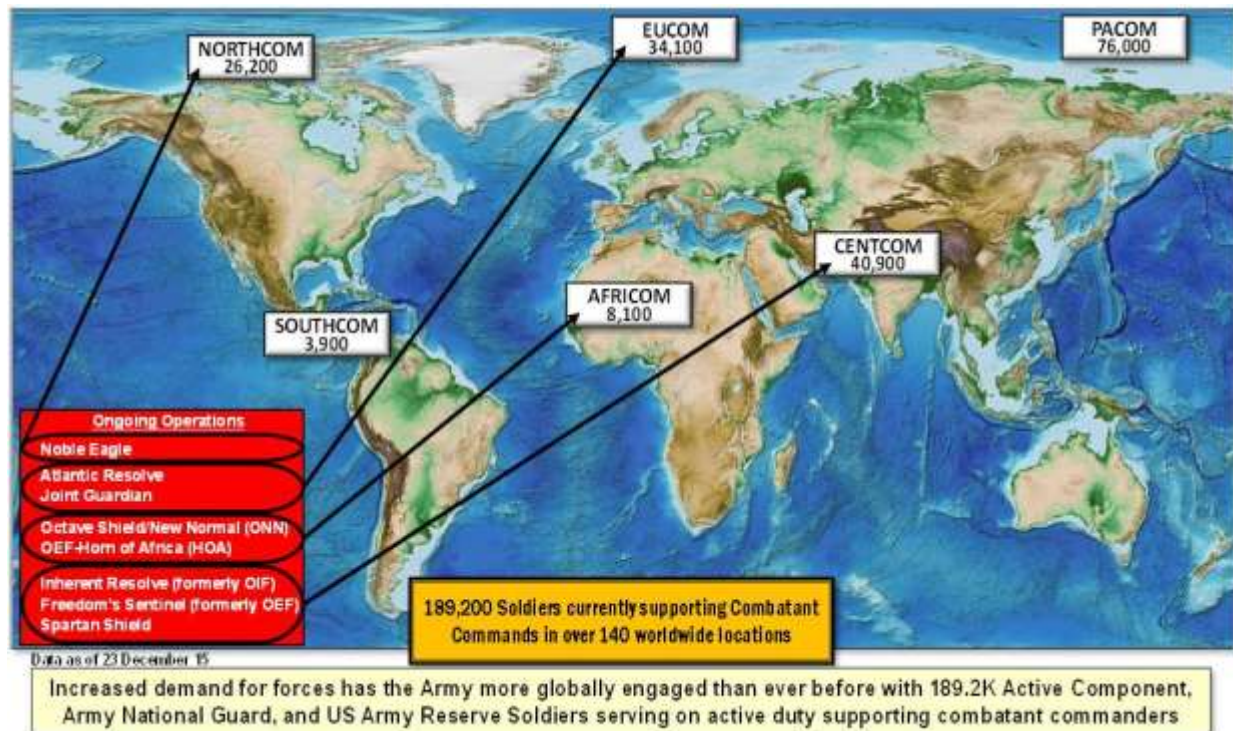
Emerging geopolitical realities confront the United States across Europe, the Middle East, Africa, and the Pacific, along with growing threats to the homeland. These realities manifest themselves in the form of increased risk to the armed forces, the country's national security interests, and the homeland. Nuclear weapon-enabled states have unabashedly expanded their territories. The potential exists for the nation to intervene with a large-scale ground force to stabilize a failed state. The real possibility exists of confronting a near-peer competitor like Russia and China, while simultaneously opposing the aggression of regional powers and transnational terrorist organizations globally. Extremist organizations have seized terrain in Iraq and Syria and, on November 13, 2015, attacked Paris, the capital of France — one of the nation's longest standing allies. As the nation has recently witnessed, the homeland is no longer a sanctuary and adversaries are investing resources to extend their capabilities to attack national security interests and even the homeland. These threats can come without warning and require the nation's Army to stay on point and always be prepared to respond to an ever growing range of contingencies from low to high intensity. This new reality will increase the demand for land forces and the enabling capabilities the U.S. Army brings to the joint force.

Near-peer competitors continue to act in an unexpected, bold manner. Russia considers the United States and the expansion of the North Atlantic Treaty Organization (NATO) a direct threat to its territory and core interests. Russia's November 2015 actions in Syria led to a direct confrontation with Turkey, a member of NATO. While the Army cannot predict Russian intentions, their record of aggression — Estonia (2007), Georgia (2008), and Ukraine and Crimea (2014) — suggests the Army needs to be prepared to face a nation-state threat on land.

Overview – FY 2017 Defense Budget

In the Pacific, China continues its territorial claims and expansion in the South China Sea. China's actions impede freedom of navigation and the ability of the joint force to project power in the Asia-Pacific region. Meanwhile, North Korean nuclear and missile developments continue to pose a direct threat to regional security. Across the Middle East and the CENTCOM area of responsibility, instability ensues. Most recently, Iranian naval vessels conducted rocket tests in December 2015 near U.S. warships and commercial traffic passing through the Strait of Hormuz, causing new tension between the two nations.

America's Army – Globally Committed



Near-peer competitors continue to act in an unexpected, bold manner. Russia considers the United States and the expansion of the North Atlantic Treaty Organization (NATO) a direct threat to its territory and core interests. Russia's November 2015 actions in Syria led to a direct confrontation with Turkey, a member of NATO. While the Army cannot predict Russian intentions, their record of aggression — Estonia (2007), Georgia (2008), and Ukraine and Crimea (2014) — suggests the Army needs to be prepared to face a nation-state threat on land. In the Pacific, China continues its territorial claims and expansion in the South China Sea. China's actions impede freedom of navigation and the ability of the joint force to project power in the Asia-Pacific region. Meanwhile, North Korean nuclear and missile developments continue to pose a direct threat to regional security. Across the Middle East and the CENTCOM area of responsibility, instability ensues. Most recently, Iranian naval vessels conducted rocket tests in December 2015 near U.S. warships and commercial traffic passing through the Strait of Hormuz, causing new tension between the two nations.

In addition to near-peer states, the Islamic State of Iraq and the Levant (ISIL), Al-Qaeda, Boko Haram, and other transnational terrorist groups present a significant threat to global stability. The ISIL is considered one of the most lethal and destabilizing terrorist group in history. Their ability to seize and hold territory, expand their reach globally, and spread their ideology through social media has challenged conventional thinking on the nature of war. Even when ISIL is defeated, terrorism will never be the same.

Today, state and non-state actors are working together to destabilize major regions of the world by combining conventional and irregular warfare. Acts of aggression occur through surrogates, cyber and electronic warfare, and economic coercion. These groups are often able to mobilize people and resources in unconventional ways that enable the hostile actors to be more agile than the response of traditional militaries. Because of these advantages, it is likely this form of conflict will persist well into the future. In addition to the global responsibility to respond to near-peer competitors and terrorism, the Army must maintain an enduring capability to protect the homeland. Continued efforts in cyber defense and partnership with the intelligence community have precluded a terrorist event similar to 9-11; however, terrorist attacks such as those that occurred in San Bernardino and Chattanooga appear to be on the rise.

Bold actions of near-peer states and transnational terrorist groups, and terrorist attacks on the homeland and world-wide demand the Army be ready now and always to meet the nation's security challenges. It is probable the next crisis will be at an unanticipated time in an unforeseen place, and will unfold in an unforeseen manner but, nonetheless, it will require the rapid commitment of Army forces. A ready Army — trained, modernized, and well led across the full spectrum of operations — is the key to success.

Further, one of the most important global security structures is the U.S. network of security alliances and partners. This valuable asset to U.S. national security and global stability is entering a period of transition. Traditional allies in Europe face significant economic and demographic burdens that exert downward pressure on defense budgets. As a consequence, allies and partners who have joined the United States in past coalition operations may be less capable to do so in the future. Building the security capacity necessary for regional stability requires sustained and focused engagement. Active engagement with allies, friends, and partners is resource-intensive but essential to sustaining global multilateral security. This combination of threats and conditions creates an increasingly dangerous and unpredictable operational environment and underscores the need for a U.S. Army that is agile, responsive, and regionally engaged.

Fiscal Environment

Fiscal austerity had a detrimental impact on readiness and modernization of the nation's Army, forcing the delay of critical investments in next generation capabilities and immediately impacting the current readiness of the force. Necessary levels of readiness are achieved only through the cumulative training that spans a continuum of time and training events. The Army had to break that continuity of training required to maintain an Army at a desired state of readiness. Although the BBA15 provides some measure of predictability, it neither prevents the possibility of a government shutdown or continuing resolution in any year, nor revises the defense funding caps established in the BCA of 2011 for FY 2018 to FY 2021. Absent additional legislation, the sequestration funding levels will return in FY 2018, forcing the Army to consider additional continued reductions in readiness and sustainment funding at a time when the nation needs the Army to rebuild readiness capabilities and get on a glide path of consistent funding levels year after year. The inability to invest in the future force affords potential adversaries the time to achieve near parity to any technological advantages the US Army has today. The more immediate impact is the increased risk of sending insufficiently trained and equipped Soldiers into harm's way — a redline the Army and the United States must not cross.

To prevail in an increasingly uncertain world, the Army's top budget priority is building and maintaining readiness. Although the Army appreciates the short-term predictability provided by the BBA15, funding levels do not keep pace with the reality of the strategic environment and increasing world threats to U.S. national security. Years of unpredictable budget levels, the seesaw funding of successive BBAs, and late receipt of appropriations exacerbates the

challenges by delaying training and maintenance, deferring investments, and ultimately degrading readiness.

The Army is fully engaged in seeking to strike a balance between resources, capabilities, and capacity, and achieving the highest levels of fiscal responsibility and stewardship. In that regard, the Army has made many tough choices. There are critical cost-saving measures that allow the Army to further reallocate scarce resources to ensure Army forces remain as trained and ready as possible. These include compensation reform, sustainable energy and resource initiatives, the Aviation Restructure Initiative (ARI) and the desire for a new round of Base Realignment and Closure (BRAC). The Army asks Congress to support these initiatives as they provide the necessary flexibility to manage budgets to achieve the greatest possible capability. Barring support for these initiatives, the Army will be compelled to make deeper reductions to manpower, modernization, and training, thereby sub-optimizing resources and inflicting greater, more prolonged damage to Army capacity and capabilities.

The Foundation of America's Defense

While the Army trains to fight alongside the Navy, Marine Corps, Air Force, Coast Guard, and the nation's allies, the nation relies on a ready Army to provide unique capabilities upon which the entire system of defense depends. As the foundation of the joint force, the Army provides critical capabilities — command and control, communication, intelligence, logistical support, and special operations — in support of joint operations to counter acts of aggression, combat terrorism, and defend the homeland. Effective joint operations against any land threat will not be possible without ready Army ground combat forces and critical enablers. The Army also devotes a sizeable portion of its force structure to sustaining Army units and other Military Department forces and multinational allies. A properly sized and equipped Army makes it possible to deploy in sufficient scale and duration to prevent conflict, shape security environments, create multiple options for responding to and resolving crises, and winning decisively.

Readiness: Ready to Fight Tonight

Today's Army is the product of the decisions made to support Soldiers in harm's way for over a decade of conflict that was marked by a focus on counterinsurgency and counter terrorism. The result is a land force of seasoned combat professionals leading today's Army, trained to fight lethal, adaptive enemies among civilian populations. The tradeoff has been that many Army leaders have had to delay or forego planned professional education and have not experienced full spectrum training (decisive action) while in key leadership positions throughout their careers to support urgent and emerging overseas contingency operations. The Army had to prioritize training for counterinsurgencies at the expense of combined arms maneuver against a near-peer enemy. The Army's equipment for meeting a near-peer adversary is still the legacy equipment used three decades ago to remove Iraqi forces from Kuwait in 1991. Unlike the 1990s, the security environment has continued to place significant demands on Army formations, stressing the Army's ability to train the forces for their core missions. In addition, potential near-peer adversaries studied the U.S. military and coalition actions in Afghanistan and Iraq and adjusted their military strategies. The decisions and tradeoffs the Army made to man, train, and equip the nation's Army while at war shape the Army of tomorrow, challenging leaders to strike a balance between end strength, readiness, and modernization, all impacted by suppressed and unpredictable future funding levels for the force.

Over the past several years and into the near future, the Army has reduced its end strength and delay modernization programs to fund readiness. Reduced funding levels force the Army to make the deliberate tradeoff between quantity and quality. This is achieved by striking a near-term balance among the four pillars of readiness — manning, training, equipping, and

leading. Achieving this balance is fundamental to providing combatant commanders the trained and ready land forces they require to be successful for current operational missions and potential major war plan contingencies.

The first pillar of readiness, manning, is about people, the keystone to innovation, versatility, and capabilities. In contrast to the Navy and the Air Force, which are platform based, the collective strength of the Army is people. The Army provides support to Soldiers, their families, and the civilian workforce by sustaining quality accessions, providing challenging opportunities, and ensuring quality-of-life programs. America's Army must continue to recruit and develop quality Soldiers, challenged by competent leaders who possess fully developed combat skills and values fundamental to the profession of arms. Manning also requires an appropriate mix of forces across the Total Army – Regular Army, Army National Guard, and the Army Reserve - to accomplish the nation's military objectives. To support Joint Force commitments worldwide, the Army must rely more heavily and increase the operational use of the Army National Guard and the Army Reserve. With the support of Congress, the Army can maintain the appropriate force mix with the requisite readiness to maintain a credible deterrent and provide the nation the capacity to conduct sustained land combat operations.

Training is the capstone pillar that integrates all other supporting elements to build and sustain overall unit readiness and, ultimately, the Army's strategic readiness to enable the Joint Force. Training ensures Soldiers and units achieve and maintain a qualitative edge in combat. This ensures that Army personnel and units remain at the forefront of thinking on how to employ and maneuver forces on the battlefield of the future and conduct decisive action – the continuous, simultaneous combinations of offense, defense, and stability or defense-support of civil authorities. The capstone of this symbiotic relationship is a unit's rotation at one of the Army's Combat Training Centers (CTCs). In FY 2015, the Army conducted 19 major training operations at CTCs, of which 15 were solely focused on the rebuilding of decisive action readiness throughout the Total Force. In FY 2016, the Army will conduct the same total amount of rotations with 16 fully focused on decisive action operations and by FY 2017, the Army will focus all 19 CTC rotations on regaining proficiency in decisive action by FY 2020. A commitment to full spectrum training at the Army's CTCs enables the Army to provide the Joint Force with the capability to out-maneuver the enemy and attack enemy forces so that the nation can prevail against threats to the homeland, the nation's interests, and its allies.

Equipping is and will continue to be a critical pillar of readiness. At the expense of the other components of readiness, the Army has not been able to afford and sustain the force with the most modern equipment. Instead, the Army will continue to selectively modernize equipment to provide Soldiers with the best equipment available and affordable. Equipping includes maintaining the Army's current inventory to include the Army Pre-Positioned Stocks (APS). Fiscal realities have forced the Army to choose to delay several modernization efforts and prioritize those programs most critical to ensuring the Army has the capability to defeat an act of aggression by a near-peer.

The first three components of readiness can only achieve the end result when a quality leader is put in charge of their integration, thereby making leader development, which requires continued predictable funding, the fourth and perhaps the most critical pillar of Army readiness. Developing Army leaders who are trusted to impose the will of the nation provides a strategic edge that neither technology nor weapons can replace. As stated in the 2015 National Military Strategy, "military and civilian professionals are our decisive advantage." It takes time to develop decisive action experienced leaders who can successfully take a trained and equipped unit into combat. Army leaders must be technically and tactically full spectrum proficient, innovative, and committed to life-long learning. The Army develops leaders within a framework of formal training and operational assignments. Professional military education serves as the

principal way Soldiers combine decisive action experiences gained during operational assignments with new doctrinal methods to enhance their readiness for combat.

As described in the four pillars of readiness, ensuring a trained and ready Army takes time and resources and can only be achieved through the cumulative effect of consistent, multiple, and repetitive training activities. The demand for Army forces continues to increase, making it important for the Army to be prepared to respond to contingencies and the escalating uncertainty in the global security environment. Currently, the Army supports operations in Afghanistan, Iraq, Kosovo, the Horn of Africa, and the homeland. The Army also has permanent and rotational forces in Germany and Korea. Since the fall of the Berlin Wall in 1989, the Army has been the “force of choice” for unforeseen operations domestically and around the world. Only with the appropriate level of resources for manning, training, equipping, and leader development can the nation ensure it has a trained and ready Army to fight and win the nation’s wars.

Modernization: Equipped to Fight

The Army will rebalance readiness and modernization from 2020 to 2030, but the Army does not have the resources to equip and sustain the entire force with the most modern equipment. Informed by the Army warfighting experiments, the Army will selectively modernize and invest in programs with the highest operational return, and build new equipment only by exception. The Army is forced to accept some risk and delay procurement of the next generation platforms until they are affordable. The Army’s modernization strategy is focused on five programs: Joint Light Tactical Vehicle (JLTV), Warfighter Information Network-Tactical (WIN-T), Patriot, AH-64 Apache, and the Armored Multi-Purpose Vehicle.

The Joint Light Tactical Vehicle is the centerpiece of the Army’s Tactical Wheeled Vehicle modernization strategy. The JLTV will replace approximately one-third of the light-wheeled vehicle fleet by 2041. This multi-mission vehicle will provide protected, sustained, and networked mobility for personnel and payloads across the full range of military operations.

The second program, Warfighter Information Network-Tactical (WIN-T), provides lighter, more mobile command communication structures, securely connecting Soldiers with uninterrupted global access to combat information that allows commanders in the field to make informed, timely decisions. In 2014, WIN-T provided the communications framework for humanitarian operations responding to the Ebola epidemic in West Africa. The WIN-T is a proven vital system that provides a demonstrated advantage in distributed communications well into the next decade.

Over one-half of Army forces are forward stationed. The Patriot provides a critical, sustained, and ground based tactical ballistic missile defense capability to deter threat advances, protect vital assets, and protect deployed Soldiers, Sailors, Airmen, and Marines as well as multinational partners. The primary update to Patriot is a significant upgrade to the radar that will provide a 360-degree view of the battlefield and increase the reach of its missiles.

Like the Patriot, upgrades to the Army’s heavy attack helicopter, the AH-64 Apache, incorporate new-technology additions or upgrades. Apache updates include improved flight performance, reduced maintenance costs, updated sensors and electronics, and the ability to control unmanned aerial vehicles as part of manned-unmanned platform teaming.

The fifth program, the Armored Multi-Purpose Vehicle (AMPV), replaces the one armored vehicle that has been in the Army’s formation since the Vietnam War. As a replacement for the M113 family of vehicles, the AMPV provides command and control, medical evacuation, medical treatment, and mortar capability, and accomplishes general-purpose tasks such as logistical resupply escort — a critical component of Army support to the Joint Force.

These five priority modernization programs provide the Army with the capability to conduct decisive action in support of the Joint Force in the near term. As the advantage of these five modernization efforts continues to diminish, the Army is actively seeking suitable replacements. Currently, the Army is prioritizing its Research Development and Acquisition (RD&A) strategy to identify key capabilities that address critical gaps in mobility, protection, and lethality of combat platforms. The Army will also continue to invest broadly in Science, Technology, and Innovation to find leading edge technologies that will lay the foundation and drive future capabilities. The Army seeks congressional support for the programs in the RD&A strategy now so that the Joint Force can meet the nation's future mission requirements.

Future Army

Ensuring that future Army forces are prepared to win in a complex world requires a focused, sustained, and collaborative effort across the institutional Army, the operating force, the joint community, industry, academia, and other inter-organizational and multinational partners. Future force development must also integrate efforts across doctrine development, organizational design, training, materiel development, leader development and education, personnel management, and investments in facilities. While concepts aligned with the Army's warfighting functions (mission command, intelligence, movement and maneuver, fires, engagement, sustainment, maneuver support and protection) help identify required capabilities for future Army forces, what is most important is to understand how units and leaders combine capabilities across warfighting functions to accomplish the mission. The Army Warfighting Challenges (AWFCs) provide an analytical framework to integrate efforts across warfighting functions while collaborating with key stakeholders in learning activities, modernization, and future force design.

Future funding levels under sequestration will lead to even greater risk, specifically limiting readiness to committed forces only and returning the Army to tiered readiness that significantly impacts the Army's ability to deter or deny near-peer adversaries. The sequestration funding levels also threaten the Army's modernization, requiring the Army to end, restructure, or delay virtually every RDA program and preclude any new investment in future capabilities. Should the sequestration funding levels remain for FY 2018, the Army will be forced to further reduce force structure and end strength by an additional 60,000 across all three components from 2017 to 2021. The Army is witnessing numerous planning assumptions that have not materialized, ranging from the number, duration, location, and size of future force conflicts, to the need to conduct post-conflict stability operations. The sequestration level funding caps will significantly increase risk by reducing the Army's ability, on any scale, to support the Joint Force in conducting simultaneous operations, specifically deterring in one region while defeating in another.

Conduct Combined Arms Operations

Army forces are essential components of joint operations that create sustainable political outcomes while defeating enemies and adversaries who challenge U.S. advantages in all domains: land, air, maritime, space, and cyberspace. Joint operations are critical to cope with such complexity, and the Army's contribution provide unique capabilities and multiple options to the President, Secretary of Defense, and combatant commanders. These capabilities include tailorable and scalable combinations of special operations and conventional forces, regionally aligned and globally responsive combined arms teams, and foundational theater capabilities to enable joint operations. Operations against elusive and capable enemies demand an extension of the concept of combined arms from two or more arms or elements of one Military Department to include the application of joint, inter-organizational, and multinational capabilities. Combined arms operations create multiple dilemmas for the enemy. Army forces achieve surprise through

maneuvering across strategic distances and have the mobility, protection, and firepower necessary to strike the enemy from unexpected directions. In high anti-access and area denial environments, dispersion allows future Army forces to evade enemy attacks, deceive the enemy, and achieve surprise. Even in dispersed operations, mobile combined arms teams are able to concentrate rapidly to isolate the enemy, attack critical enemy assets, and seize fleeting opportunities. Forces conduct continuous reconnaissance and security operations to seize, retain, and exploit the initiative over the enemy while protecting the force against dangers. During joint operations Army forces maneuver and project power across all domains to ensure joint force freedom of action and deny the enemy the ability to operate freely across those domains. Army leaders synchronize the efforts of multiple partners across multiple domains to ensure unity of effort.

Take Care of Soldiers, Civilians, and their Families

Just as the strength of the nation is the American people, the strength of the Army — its Soldiers — are the nation's sons and daughters who volunteer to serve as Soldiers. The Army's collective strength originates from the quality people we recruit, develop, and eventually reintegrate into communities across America. Building Soldier readiness includes filling Army formations with ethical, moral, and competent Soldiers who are mentally and physically fit to withstand the intense rigors of ground combat.

Having ready Soldiers makes the nation stronger. The Army remains committed to providing Soldiers, civilians, and their families the best possible care, support, and services. The Army continues to improve access and predictability of services across the spectrum of wellness — physical, emotional, social, family, and spiritual. This past year, for example, the Army established a policy that began placing substance-abuse counselors within the mental health clinics supporting combat brigades. Another example is the ongoing Soldier for Life program that ultimately connects Army, governmental, and community efforts to build relationships that facilitate successful reintegration of Soldiers, Retired Soldiers, Veterans, and their Families into communities across America. Renewed capital investments that provide Soldiers with ever-increasing education opportunities, access to meaningful employment, and quality healthcare ultimately improve the quality of life, enhance readiness, and protect the health and well-being of those who serve.

The process of building Army readiness occurs on Army installations where Soldiers live, work, and train. On the 154 permanent Army installations worldwide that many Soldiers call home, the availability of quality ranges, maneuver areas, airfields, and classrooms enables the Army to integrate diverse individual skills and attributes into ready Army units. Responsibly managing in excess of 13 million acres, twice the land mass of the state of New Jersey, requires the Army to continually improve installation operations. A smaller force requires the Army to match the best quality facilities to the requirements of the mission. The Army will realign organizations with enduring missions to leverage the best facilities. The Army's excess infrastructure hinders the ability to effectively resource decisive readiness, project power, and sustain the all-volunteer force. Continued investment in installations readiness and Soldier and Family programs plays a key role in ensuring Army readiness as well as attracting and retaining the best Soldiers, civilians, and their families.

From the Secretary of the Army to the youngest private, the Army remains committed to ensuring the dignity and respect of Soldiers, civilians, and their families. A part of that respect is ensuring every Soldier and civilian has the opportunity to reach their highest potential. With the recent opening of all military occupations and positions to women, the Army will have access to a broader range of talent. The Army will provide every Soldier and civilian equal opportunities to rise to the level of their merit regardless of their gender, their race, or their self-identity.

Overview – FY 2017 Defense Budget

The Army continues to attract the nation's premier young men and women, despite having to execute a variety of drawdown programs. Through officer and enlisted accession programs, the Army will continue to recruit the most talented Soldiers with the capabilities, prerequisites, and potential required for future needs. While the Army projects achievement of its FY 2016 recruiting goals, the incentives, advertising, and marketing resources that the Army expends directly determine how many people join the Army. Funding makes recruiting possible.

From an individual's first to last day in the Army, the Army will not tolerate sexual assault or sexual harassment. The Army actively pursues methods to eliminate sexual harassment and sexual assault by creating a climate that respects the dignity of every Soldier, civilian, and family member. While the primary objective of the Army Sexual Harassment/Assault Response & Prevention (SHARP) program is prevention, when an incident occurs, the Army is committed to providing best-in-class support and protection of the survivor. The Army performs assessments of the SHARP program strategies to measure effectiveness, identify gaps, and make adjustments as required. Last year, the Army identified a potential gap in immediate care data collection. Accordingly, the U.S. Army Medical Command established a Sexual Assault Medical Management Office that provides at least one sexual assault nurse examiner at every Military Treatment Facility with a 24/7 emergency room. Eliminating sexual assault and sexual harassment ensures that Soldiers are ready for combat.

It is through changes in personal conduct and proactive leadership that the Army seeks to prevent unwanted or unprofessional acts. The Army's most precious asset is its people; therefore, the well-being of Soldiers, civilians, and their family members, both on and off-duty is imperative to the Army. Historically, the Army's training has focused on eliminating negative behaviors and minimizing risk factors. Now the Army also focuses on improving personal readiness. Pledges like "Not in My Squad," championed by Sergeant Major of the Army Dailey, empower Army leaders who have direct influence over their Soldiers every day to take ownership of Army values and standards. The American people expect and continue to deserve an Army of professionals they can trust.

Conclusion

Today's Army, sufficiently manned, trained and equipped, is a necessity to address the security environment. With the full support of Congress, the Army will be ready to respond to the challenges that face the nation as the Army has done for over 240 years. Whether deterring aggression along the Korean Demilitarized Zone, advising and assisting in Afghanistan, or protecting the homeland, Soldiers stand ready to protect the nation's interests. The Army's capacity and capabilities serve as a foundation of the Joint Force that exists for one purpose: to fight and win wars in defense of the United States.

Continued investment in all aspects of readiness is the primary means that allows the Army to meet the priorities of the combatant commanders and maintain the capacity to respond to threats worldwide. Only by building readiness and modernizing our equipment throughout the Total Army, can the Joint Force respond to unforeseeable threats, decisively defeat the nation's enemies, and enforce the nation's will.

The collective strength of the Army depends upon the Soldiers, civilians, and their families who comprise it. Army values, including treating others with respect and leading with integrity, represent collective strength. Taking care of the troops ensures Soldier readiness and provides the means to recruit and retain Soldiers and civilians.

America does not need the largest Army in the world, but it must have the most capable Army, right sized to address the security environment now and in the future. In light of today's budget reality, the Army continues to prioritize readiness at the expense of modernization to address

current demands to support the nation's global commitments and protect the homeland. The Army requests the support of Congress to sufficiently fund and modernize America's Army to ensure the Army remains the preeminent fighting force able to meet current demands and protect the nation's security interests. The American people will continue to judge the Army on one standard: when called upon to fight and win, the Army will be mission ready and victorious.

DEPARTMENT OF THE NAVY OVERVIEW

The United States of America is a maritime nation. For more than two centuries, the Navy and Marine Corps — the Sea Services — have operated throughout the world to protect American citizens and defend U.S. interests by responding to crises and, when necessary, fighting and winning wars.

Forward-deployed and forward-stationed naval forces use the global maritime commons as a medium of maneuver, assuring access to overseas regions, defending key interests in those areas, protecting citizens abroad, and preventing adversaries from leveraging the world's oceans against the United States. The ability to sustain operations in international waters far from the nation's shores constitutes a distinct advantage for the United States — a Western Hemisphere nation separated from many of its strategic interests by vast oceans. Maintaining this advantage in an interconnected global community that depends on the oceans remains an imperative for the sea services and the nation.

Today's global security environment is characterized by the rising importance of the Indo-Asia-Pacific region, the ongoing development and fielding of anti-access/area denial (A2/AD) capabilities that challenge U.S. global maritime access, continued threats from expanding and evolving terrorist and criminal networks, the increasing frequency and intensity of maritime territorial disputes, and threats to maritime commerce, particularly the flow of energy.

In addition to the risks emerging in this turbulent 21st Century, there are opportunities as well - many facilitated by the sea services through routine and constructive engagement with allies and partners. Chief among them is the potential for a global network of navies that brings together the contributions of like-minded nations and organizations around the world to address mutual maritime security challenges and respond to natural disasters.

The U.S. sea services uniquely provide forward postured capability around the globe. During peacetime and times of conflict, across the full spectrum — from supporting an ally with humanitarian assistance or disaster relief to deterring or defeating an adversary in kinetic action - Sailors and Marines are deployed at sea and in far-flung posts wherever and whenever needed. Coming from the sea, the sea services get there sooner, stay there longer, bring along everything needed, and don't have to ask anyone's permission.

The founding fathers recognized the United States as a maritime nation and the importance of maritime forces, including in the Constitution the requirement that Congress "maintain a Navy." In today's dynamic security environment, with multiple challenges from state and non-state actors that are often fed by social disorder, political upheaval, and technological advancements, that requirement is even more fundamental.

The sea services' responsibility to the American people dictates an efficient use of fiscal resources and an approach that adapts to the evolving security environment. Supporting its people, building the right platforms, powering them to achieve efficient global capability, and developing critical partnerships are key.

Overview – FY 2017 Defense Budget

The FY 2017 budget request balances current readiness needed to execute assigned missions while sustaining a highly capable fleet and allows the Department of the Navy (DoN) to take calculated risk in balancing today's requirements and those required to counter emerging threats. In the near term, there are gaps in training and maintenance that create readiness risks in the event of a major contingency. In the longer term, there are also risks associated with a dynamic and increasingly dangerous security environment, especially as potential adversaries develop greater military capability, and smaller forces strain to handle multiple simultaneous contingencies. This budget reflects a Future Years Defense Program (FYDP) from 2017 to 2021 of \$826.4 billion in the base budget, \$1.6 billion higher than the FYDP presented with the FY 2016 budget; the FY 2017 budget for the DoN is \$155.4 billion, a decrease of \$8.2 billion (5 percent) from the FY 2017 plan in the FY 2016 budget request. The OCO request for FY 2017 is \$9.5 billion.

The FY 2017 budget request supports the construction funding for 38 ships across the FYDP. Providing stability in shipbuilding to affordably deliver warfighting requirements, the budget supports steady production of destroyers and submarines; ten destroyers and nine submarines are constructed through FY 2021. The FYDP shipbuilding construction program also includes funding for the Ohio Replacement Program Advanced Procurement beginning in FY 2017, one LHA amphibious assault ship replacement, four T-AO(X) fleet oilers, and continued funding for the refueling and overhaul of USS GEORGE WASHINGTON (CVN 73). The FY 2017 budget request also funds two littoral combat ships (LCS) and continues to finance the detailed design and construction of the second *Ford* Class aircraft carrier and provides the second year of Advanced Procurement for the third.

The budget supports a balanced manned and unmanned aviation procurement plan of 476 aircraft over the FYDP. The successful testing of the carrier variant (CV) of the F-35 Joint Strike Fighter (JSF) on USS NIMITZ (CVN-68) in 2014 followed by the successful operational testing of the short take off and vertical landing (STOVL) variant on the USS WASP (LHD-1) in 2015 continues JSF program progression. The F-35B reached initial operational capability in July 2015 with a squadron of 10 ready for deployment worldwide. The DoN will procure 161 JSF aircraft of both Navy and Marine Corps variants across the FYDP. The Marine Corps invests heavily in rotary wing aircraft, accelerating the procurement of the final 78 AH-1Z-1/UH-1Y Cobra helicopters, and procuring 24 MV-22 Ospreys. The first 24 Navy V-22 Carrier Onboard Delivery (COD) aircraft will be procured starting in FY 2018. Investment in unmanned systems includes 19 MQ 4 Triton Unmanned Aircraft Systems through FY 2021, with first deployment to the Pacific in FY 2017, and the procurement of 9 MQ-8C Vertical Takeoff Unmanned Aircraft Systems. Aviation investments in the FYDP also include procurement of airborne early warning aircraft (23 E-2D), presidential helicopters (17 VH-92A), heavy lift helicopters (40 CH-53K), aerial refueling tankers (10 KC-130J), and the final 30 P-8A Poseidon multi-mission maritime aircraft.

The FY 2017 budget request funds an FY 2017 fleet of 272 Battle Force Ships. As with the FY 2016 request, this budget funds baseline and OCO flight hours for the Navy and Marine Corps to deploy at a 2.0 T-rating, which indicates the Aviation Training and Readiness (T&R) score for requirements and resources. Ship depot maintenance is funded to 70 percent in the base budget and 100 percent with OCO. Aviation depot maintenance is funded to capacity at the Fleet Readiness Centers, 85 percent of the total requirement in base plus OCO funding (76 percent in base). Marine Corps ground equipment maintenance is funded in base plus OCO at 79 percent of requirement. The FY 2017 base budget request funds sustainment of Navy and Marine Corps shore facilities at 70 percent.

To provide the required ability to deter aggression and respond to emerging security threats - including extremist organizations, pandemic diseases and natural disasters — the sea

Overview – FY 2017 Defense Budget

services must maintain the proper force strength. Both the Navy and Marine Corps are on path to align with the force structure required by strategy, following periods of reduction. The Navy has drawn down from 383,000 in FY 2002 and will end the FYDP at 323,100. The Marine Corps is coming down from a peak of 202,000 in FY 2009 to a sustained level of 182,000 in FY 2017 and beyond. The Marines have returned to their expeditionary roots, with an enhanced ability to operate from sea. Civilian personnel levels will slightly increase, strongly supporting the force as engineers, scientists, medical professionals and skilled laborers.

The DoN remains challenged to meet combatant commander demands for forces and associated higher-than-planned operational tempo over the past decade while dealing with constrained funding levels. The capacity to surge forces has decreased due to high operating tempo and deferred maintenance, a reduction in aircraft and weapons procurement, and risks taken against support infrastructure. This budget continues to put a priority on readiness while maintaining the minimum investment necessary to maintain an advantage in advanced technologies and weapons systems. While the DoN has accepted some risk in weapons capacity and delayed certain modernization programs, this budget request provides a plan to keep the Navy and Marine Corps as a ready, balanced force. The DoN prioritizes investments in modernization efforts to recapitalize the forces and maintain an effective, safe, and secure nuclear deterrent, including weapons and systems to enhance reliability and survivability of the nuclear strike capability and C2 networks.

Overall, the DoN's investments in readiness and infrastructure in the FY 2017 budget request are essential to generating the combat ready forces that support the DoD rebalance to the Asia-Pacific and enable critical presence in the strategic maritime crossroads that span the Middle East, Europe, Africa, the Western Pacific, and South America.

Strategic Guidance

The FY 2017 budget request is developed from the priorities established in the Quadrennial Defense Review (QDR) 2014, which identifies ten missions, arranged under the three QDR objectives — protect the homeland, build security globally, and project power and win decisively.

Protect the Homeland

- Maintain a safe, secure, and effective nuclear deterrent
- Fight terrorism through counter-terrorism/irregular warfare operations
- Defend the homeland and provide support to civil authorities
- Counter weapons of mass destruction

Build Security Globally

- Provide a stabilizing presence across the globe
- Conduct stability and counterinsurgency operations
- Conduct humanitarian, disaster relief, and other operations

Project Power and Win Decisively

- Defer and defeat aggression
- Project power despite anti-access/area denial challenges
- Operate effectively in space and cyberspace

In addition to these three objectives and ten missions, the QDR also directs the DoN to prepare for emerging conflicts and to maintain the strength of the All-Volunteer Force. The Marine Corps will return to a smaller, more agile sea-based force, as outlined in “Expeditionary Force 21.” The DoN will also evaluate innovative ways to integrate Marine Corps operations with Navy, Coast Guard, Special Forces, and international partners.

The DoN has identified three major forces that energize the rapidly changing environment in which the Navy must operate to fight and win. The first is increased traffic on the oceans, seas, waterways, and the sea floor. The maritime system is becoming more heavily used, stressed, and contested than ever before. The second force is the increasing rise of the global information system, including information that rides on servers, undersea cables, satellites, and wireless networks that connect the globe. The third force is increasing rate of technological creation and adoption, including robotics, energy storage, 3-D printing, and low-cost networks. The Navy will need to respond with greater agility and creativity across the entire spectrum of action at and from the sea.

The DoN will move forward to address these forces by executing four lines of effort that focus on warfighting, learning better and faster, strengthening the Navy team, and building partnerships. The Navy will enhance power at and from the sea by providing a combat-ready fleet, trained and deployed to protect U.S. interests while deterring conflict. The DoN will learn better and faster by employing best techniques and technologies to accelerate learning and adapting processes to be inherently receptive to innovation and creativity. The DoN will strengthen the Navy team of Sailors and Civilians who are trained masters of their craft, who share core values, and are empowered to use their own initiative. The Navy will expand and strengthen the network of partners by building enhanced operational relationships with other services, agencies, industry, allies and partners who support shared interests.

People, Platforms, Power, and Partnerships

Four key factors sustain the DoN’s warfighting advantage and global presence; these factors are the Secretary of the Navy’s priority areas:

- **People** provide the critical asymmetric advantage in today’s complex world. The DoN will continue to prioritize the correct size of deployment capabilities to meet operational demands, support new concepts and stratagems to develop at all levels, and to ensure the proper training, readiness, and mental and physical well-being of Sailors, Marines and their families.
- **Platforms** span the ships, aircraft, submarines, tactical vehicles, and unmanned vehicles that provide the capability and capacity underpinning the DoN’s global combat-ready presence. The budget request supports expanding aspects of information warfare, specifically in the areas of space and cyber security. This approach is essential to providing the platforms needed to execute DoN missions.
- **Power** and energy get the platforms where they need to be and keep them there. The DoN continues to make progress toward greater energy security, building on a record of alternative energy long term innovation from sail to coal to oil to nuclear to biofuels, wind, and solar power.
- **Partnership** strengthens the capacity of existing partnerships, while developing key alliances through initiatives, joint exercises, operations, and broad leadership engagement. This has allowed the DoN a more interoperable force better prepared and more widely available to prevent and respond to crises.

Innovation

To face the threats of tomorrow, the force must continue to evolve and innovate to meet the challenges of a changing world. National security depends on a future force that is able to harness the best and brightest talent that the nation has to offer. The Secretary of the Navy is taking the initiative to reform the Navy's personnel system to achieve a modernized force and initiating manpower reforms to modernize the Navy's personnel system. High profile changes such as new maternity leave policies, physical fitness assessment revisions, and body composition assessment reforms are accompanied by other initiatives like a more proactive outreach to retain talent and restructuring of bonuses to reward performance. The Navy is encouraging individuals, teams, and organizations to engage in high velocity learning through tools and technologies that prioritize creativity and agility. These and other changes emerging from the Sailor 2025 initiative and the Secretary of Defense's Force of the Future initiative are designed to offer careers that are flexible, option-oriented, and competitive. By leading in this area, Navy will continue to provide the exceptional manpower capable of operating the most technologically-advanced Navy in the world.

The DoN has been at the forefront of innovation for over 240 years, from the USS Constitution's inventive battle armor to ship-borne tactical aviation, nuclear powered ships and submarines, ballistic missile defense capability, and now fifth generation fighter aircraft and multi-mission ships. The Navy must continue to be a leader in rapidly deployed innovation, using high quality people, better use of information, and quicker maturation of ideas. The Navy must take advantage of opportunities from advances in technology, information systems, and the sciences. While the DoN will be ready to defend the homeland and the nation's global interests, it must continually innovate, not only to keep pace with emerging technology but also to bridge challenges in today's fiscal environment to achieve the capabilities required for tomorrow's global security. Innovation will be accomplished through five key efforts:

- Build a naval innovation network in partnership with private sector to accelerate development and fielding of new ideas and methods. Greater access to the tools, training, and technology will help transform the Navy and Marine Corps, its capabilities, and its workforce.
- Manage the talent of the DoN workforce through systems that will better inform career paths and career options and provide more flexibility. The Sailor 2025 initiative will provide high velocity learning through tools such as simulators, gaming, and other technologies that prioritize creativity as well as agility.
- Transform DoN uses of information by empowering decision makers through information sharing across organizations to enable innovation to thrive.
- Accelerate new capabilities to the fleet by creating test beds for emerging operational capabilities to accelerate delivery to the warfighter. This is necessary to keep pace with rapidly evolving technology.
- Develop game-changing warfighting concepts by increasing the frequency and breadth of DoN war gaming and applying outcomes for future capability.

Forward Presence and Partnership

Naval forces operate forward to shape the security environment, signal U.S. resolve, and promote global prosperity by defending freedom of navigation in the maritime commons. By expanding the network of allies and partners and improving the DoN's ability to operate alongside them, naval forces promote stability, deter conflict, shorten the response time to aggression, and foster the secure environment essential to an open economic system based on

Overview – FY 2017 Defense Budget

the free flow of goods. During crises, forward naval forces provide the President immediate options to defend national interests, de-escalate hostilities, and keep conflict far from the nation's shores. During wartime, forward naval forces fight while preserving freedom of access — and action — for follow-on forces.

The FY 2017 budget request provides forward postured capabilities of 119 ships by 2021, up from an average of 94 in 2016, to be “where it matters, when it matters.” This includes forward-based naval forces in Guam, Japan, and Spain, forward-operating forces deploying from overseas locations such as Singapore, and rotationally-deployed forces that operate from the United States. To provide forward presence more efficiently and effectively, the DoN continues to implement the following force employment innovations:

- Increase forward-basing of forces abroad to reduce costly rotations and deployments while boosting in-theater presence.
- Provide globally distributed and networked expeditionary forces in concert with allies and partners to increase effective naval presence, strategic agility, and responsiveness.
- Employ modular designed platforms to allow mission modules and payloads, rather than entire ships, to be swapped, thus saving time and money.

Cyber Resiliency

The DoN invests in protection of its cyber networks to operate effectively in every mission. The DoN has expanded previous investments in Operation Rolling Tide (ORT), which was primarily focused on tactical networks such as the Next Generation Enterprise Network (NGEN) and the Consolidated Afloat Networks and Enterprise Services (CANES), to include combat and other control systems on tactical platforms. The Task Force Cyber Awakening (TFCA) was established to provide a holistic view of cyber security across the Navy enterprise. Based on the TFCA's prioritizations of required capabilities to improve Navy's cyber posture, the budget request includes an additional \$300 million across the FYDP across a broad spectrum of programs. Together, ORT and TFCA efforts form the Cyber Resiliency Plan; the FY 2017 budget request will lead to significant improvements in the DoN's Cyber posture.

Conclusion

The United States will increasingly leverage its sea services in the pursuit of its national security objectives. In this turbulent world, the sea services provide the nation with credible, flexible, and scalable options to sustain freedom of the seas, rapidly respond to crises, and deter and defeat aggression. Through institutional innovation, balanced investments, and a commitment to developing our members, the DoN will build a future force that is capable and combat-ready.

Facing the challenges of the 21st Century, the DoN will remain committed to the development of its people; validate new operational concepts; and employ innovative capabilities that sustain its warfighting advantages, particularly in contested environments. Meeting these challenges requires the DoN embrace the global network of navies, becoming stronger by working with the nation's allies and partners.

The Navy and Marine Corps' foremost priority remains the security and prosperity of the nation and the American people and way of life. This strategy ensures that the Department of the Navy will continue protecting American citizens and advancing U.S. interests, as it has done for more than two centuries. American sea power — *forward, engaged, and ready*. This will be a challenge if sequestration level funding caps continue for FY 2018 through FY 2021.

DEPARTMENT OF THE AIR FORCE

Introduction

The Air Force's FY 2017 budget request is designed to preserve combatant commander requirements in support of the defense strategy. The Secretary of the Air Force's priorities of taking care of people, striking the right balance between today's readiness and future modernization, and making every dollar count continue to serve as the foundation for the FY 2017 budget request.

The Air Force's FY 2016 budget request was built to invest in critical capabilities and restore capacity to meet the combatant commanders' most urgent requirements. In FY 2017, the Air Force again seeks to balance capability, capacity, and readiness while investing in modernization and recapitalization at the funding levels required to support the defense strategy. The FY 2017 budget request of \$166.9 billion (\$151.1 billion base; \$15.8 billion OCO) is informed by current geopolitical conditions and restores some capacity, funds readiness to executable levels, and makes additional investments in nuclear, space, cyber, command and control, and intelligence, surveillance, and reconnaissance (ISR) capabilities.

The FY 2017 budget request seeks to build and maintain an Air Force that is capable of executing its core missions against future high-end threats and is ready for the full range of military operations. Airmen bring to the nation's military portfolio five interdependent and integrated core missions: (1) air, space, and cyber superiority; (2) ISR; (3) rapid global mobility; (4) global strike; and (5) command and control. While the methods for executing these missions have changed over time, the core missions have not fundamentally differed since the Air Force's inception. More information on these core missions is available in the Air Force strategic framework document, [*Global Vigilance, Global Reach, Global Power for America*](#).

FY 2017 INITIATIVES BY AIR FORCE CORE MISSION

Air, Space, and Cyber Superiority

Air Superiority

The United States and coalition forces experienced a distinct precision attack advantage in 2015 operations, such as in Afghanistan. However, potential adversaries are leveraging technologies to improve existing airframes with advanced radars, jammers, sensors, and more capable surface-to-air missile systems. Increasingly sophisticated adversaries and highly contested environments will challenge the ability of Air Force legacy fighters and bombers to engage heavily defended targets. To stay ahead of these challenges, the Air Force's FY 2017 budget balances needed precision strike capabilities. It funds modernization of legacy fighters and bombers, F-35 Joint Strike Fighter development and procurement, development of a new Long Range Strike Bomber (LRS-B) capability, modifications to the F-22 Raptor, and continued investment in preferred air-to-ground and air-to-air munitions.

Legacy Aircraft: The average F-15C/D Eagle is over 28 years old and requires modernization to remain viable. The F-15C/D models, including several funded through the European Reassurance Initiative (ERI), will undergo multiple offensive and defensive upgrades to ensure capability and survivability in the current and future threat environments, including Active Electronically Scanned Array (AESA) radars, the Advanced Display Core Processor (ADCP) II central computer, Mode 5/Automatic Dependent Surveillance-Broadcast (ADS-B), and Increment 1 and 2 development of the Eagle Passive/Active Warning Survivability System (EPAWSS). Also in initial development is an Infra-Red Search and Track system that will give

Overview – FY 2017 Defense Budget

the Eagle the passive search and track capability that is vital to operations in a contested environment. These efforts will extend the capability of the Eagle into the mid-2020's.

Additionally, the FY 2017 budget request seeks to modernize a small number of F-16 Fighting Falcons for National Capital Region support to address Homeland Defense needs. The AESA radars will be retrofitted starting in FY 2017 and, starting in FY 2018, 52 more F-16s will be upgraded with AESA radars. This modernization is necessary to guarantee the capability of the force in the mid- and long-term.

Finally, the FY 2017 budget rephases the retirement plan for the A-10 Thunderbolt II fleet to preserve Total Force fighter capacity during the Air Force's transition to the F-35, keeping the A-10 in the inventory through FY 2022.

Electronic Warfare: The FY 2017 budget maintains the current EC-130H Compass Call fleet and retains a Total Active Inventory (TAI) of 14 EC-130Hs.

Fifth Generation Aircraft: To remain viable in contested airspace and ahead of accelerating threats, F-22A combat capability modernization focuses on Increment 3.1 Operational Flight Program (OFP) with continued development of the follow-on 3.2B OFP. Increment 3.1 includes hi-resolution synthetic aperture radar, geo-location and Small Diameter Bomb I capability. When installed, Increment 3.2B will provide increased weapons capability and improved data-link. The Air Force also increased F-22 logistics support to sustain an enhanced flying hour program, which was increased from 28 thousand to 32.5 thousand hours to meet operational training requirements.

As one of the Air Force's top three acquisition priorities, the FY 2017 budget continues investment in the F-35 program. Partial funding is included for Block 4 and research and development of nuclear weapons capability.

Personnel Recovery (PR): The FY 2017 budget funds the recapitalization of the HC-130J Combat King II, increases investment in the Guardian Angel program and funds modifications for the legacy HH-60G Pave Hawk. Additionally, the Combat Rescue Helicopter (CRH), which is the HH-60 replacement, is fully funded for a projected Initial Operational Capability in 2021.

Munitions: The FY 2017 budget funds Air Intercept Missile (AIM)-9X Block 2 and AIM-120D development, integration, and production. The AIM-9X gives pilots the ability to release the missile out of X-band at the time of launch, thus decreasing the time required from target identification to firing. The AIM-120D is the next iteration of the Advanced Medium Range Air to Air Missile (AMRAAM) with increased range and radar capabilities. Although the Department will reduce its procurement quantity of AIM-9X, the additional investment in the missile's software will increase the capability of the AIM-9X inventory. The Air Force will also marginally increase AIM-120D procurement from the FY 2016 PB levels across the FYDP.

The FY 2017 budget request continues procurement of the Guided Bomb Unit (GBU)-53B Small Diameter Bomb Increment II (SDB II). The GBU-53B provides a capability to hold moving targets at risk in all weather conditions and at stand-off ranges. The SDB II is a key part of the solution for future conflicts and will be integrated onto the F-22 Raptor and F-35 Joint Strike Fighter, as well as other current operational platforms. Procurement of Advanced Guided Missile (AGM)-158B Joint Air-to-Surface Standoff Missile-Extended Range (JASSM-ER), an upgrade to the baseline JASSM, continues at an increased quantity in the FY 2017 budget. The JASSM-ER can fly a much greater distance, providing excellent stand-off capability in highly contested environments, while increasing the flexibility and lethality of the force. In FY 2016, the Air Force bought 340 JASSM-ER global strike munitions and in FY 2017 the Air Force will increase the purchase to 360 JASSM-ERs, as well as 312 SDB IIs. The AGM-114 Hellfire missile is the primary weapon for Predator and Reaper systems directly supporting Joint Force

Commanders in finding and prosecuting time-sensitive targets. Although the Air Force will reduce its procurement of AGM-114s from 3,756 (plus 2,500 with OCO funding; total planned procurement is 6,256) in FY 2016 to 284 (plus 1,252 with OCO funding; total planned procurement is 1,536) in FY 2017, the AGM-114 inventory is at maximum capacity due to several prior year reprogramming actions.

Space Superiority

Space continues to be an increasingly contested and congested environment as more commercial and government entities take advantage of space. The Air Force remains committed to improving space situational awareness and its command and control advantage, while modernizing and recapitalizing key space capabilities central to the joint fight. The FY 2017 budget request continues to enhance space investment in line with strategic direction.

Space Situational Awareness (SSA) and Space Control: The FY 2017 budget request maintains FY 2016's increased investment in SSA and Space Control capabilities to address growing threats while enhancing the ability to identify, characterize, and attribute threatening actions. These enhancements enable one-way net-centric data to the Joint Space Operations Center (JSpOC), accelerate delivery of the JSpOC Mission System Increment 3, and deliver enhanced information to enable rapid visualization and targeting. Additionally, the Department requests increased funding for the Joint Interagency Combined Space Operations Center (JICSpOC), thus laying the foundation for joint experimentation efforts and further enhancing joint tactics and doctrine for space.

Global Positioning System (GPS): The Air Force will re-phase the GPS III space vehicle procurement profile SV 11 from FY 2017 into FY 2018 to support contract competition, and realign savings from the contract re-compete to fund GPS III contingency operations and the GPS command and control ground system (OCX) to Service Cost Position (SCP) levels. Additionally, the Department increased funding for Military GPS User Equipment (MGUE) programs to accelerate platform integration of "M-code" capability, which provides stronger signaling and data authentication capability.

Satellite Architecture: The Air Force continues to explore future architectures for the Satellite Communications (SATCOM) and Overhead Persistent Infrared (OPIR) technologies. The FY 2017 request fully funds the Advanced Extremely High Frequency (AEHF) capability with vehicles 5/6 and Space Based Infrared System (SBIRS) geosynchronous orbit capability with vehicles 5/6. It also pursues a resilient, disaggregated SATCOM architecture with separate tactical and strategic systems.

Space-Based Environmental Monitoring: The Air Force commenced development of Weather System Follow-on (WSF) in FY 2015 to begin the transition from the Defense Meteorological Satellite Program (DMSP). The FY 2017 budget request matches the Service Cost Position and aligns the Air Force proposed strategy to launch an enhanced Technology Demonstration in FY 2017. The WSF will provide timely, reliable, and high quality space-based remote sensing capabilities to meet global environmental observations of atmospheric, terrestrial, oceanographic, solar-geophysical, and other validated requirements.

Assured Access to Space: The Evolved Expendable Launch Vehicle (EELV) program remains fully funded to support all competitive launch opportunities in Phase 1A, and is aligned with a satellite launch scheduled in FY 2017. A total of five launch services, including three competitive launches, will be procured in FY 2017. Additionally, the Department added funding to develop and integrate a domestically-sourced rocket engine to include new upper stages as part of the development effort.

Cyberspace Superiority

Cyberspace Superiority is the degree of dominance in cyberspace by one force that permits the secure, reliable conduct of operations by that force and its related land, air, maritime, and space forces at a given time and place without prohibitive interference by an adversary. The Air Force categorizes the Department of Defense Information Network (DODIN) Operations, Defensive Cyberspace Operations, and Offensive Cyberspace Operations as various components of the cyberspace operations. As a combatant command support agency for the U.S. Cyber Command (USCYBERCOM), the Air Force Cyberspace Superiority budget includes a fourth category for combatant command support.

This year's budget request continues the focus on the development of Cyber Mission Forces with support for defensive and offensive cyberspace operations capabilities. The unique attributes of cyberspace operations require trained and ready cyberspace forces to detect, deter, and, if directed, respond to threats in cyberspace. Securing and defending cyberspace requires close collaboration among Federal, state, and local governments; private sector partners; and allies and partners abroad.

The budget also supports defensive cyberspace operations that provide information assurance and cyber security to the Department's networks at all levels and continues to augment personnel within the combatant commands to support the integration and coordination of cyberspace operations.

DODIN Operations: The DODIN Operations are actions taken to design, build, configure, secure, operate, maintain, and sustain DoD communications systems and networks in a way that creates and preserves data availability, integrity, confidentiality, as well as user/entity authentication and non-repudiation. In DODIN Operations, the Air Force continues to plan and influence the development of the DoD Joint Information Environment (JIE). The Air Force supports the standup of the new security layer for JIE under the Joint Regional Security Stacks initiative and Air Force personnel are working with their Service counterparts, USCYBERCOM, the Defense Information Systems Agency, the DoD Chief Information Officer, and other DoD Agencies and combatant commands to shape the strategy, planning, and implementation of the overarching JIE initiative.

Defensive Cyberspace Operations: Defensive Cyberspace Operations are cyberspace operations intended to defend DoD or other friendly cyberspace. The Air Force will increase the operational capability of the Cyberspace Vulnerability Assessment/Hunter mission and will leverage the Active and Reserve Component to increase capacity by standing up additional Cyber Protection Teams.

Offensive Cyberspace Operations: Offensive Cyberspace Operations are cyberspace operations intended to project power by the application of force in and through cyberspace. The Air Force is continuing to work with the Joint Staff and USCYBERCOM to provide forces required for the National and Combat Mission Teams supporting national and combatant command objectives.

Intelligence, Surveillance, and Reconnaissance

The FY 2017 budget request represents the Air Force's commitment to medium altitude manned and unmanned capabilities, ensures viability of high-altitude conventional assets to fulfill designated wartime requirements, and continues the enterprise-wide Intelligence, Surveillance, and Reconnaissance (ISR) investment in intelligence analysis and end-to-end automation through dissemination. The FY 2017 budget request sustains focus on enhancing ISR capabilities against high-end threats while maintaining investment in medium-altitude, permissive ISR to sustain capacity for ongoing combatant command operations.

Overview – FY 2017 Defense Budget

The FY 2017 budget request includes a commitment to enhance the remotely piloted aircraft (RPA) enterprise to meet operational and training demands. This effort includes doubling the Undergraduate RPA Training budget to accommodate 394 graduates per year, up from 192 graduates per year in the FY 2016 budget.

Medium Altitude ISR: The Air Force sustains MQ-1 Predator and MQ-9 Reaper medium-altitude, permissive ISR capacity through FY 2017, with Remotely Piloted Aircraft (RPA) lines funded in the FY 2017 budget request. Additionally, the Air Force restores two operational MQ-9 squadrons previously slated for inactivation in FY 2017, normalizing the ISR capacity to align with current and enduring operations tempo.

The FY 2017 budget sustains RC-135V/W Rivet Joint and funds aspects of the RC-135U Combat Sent and RC-135S Cobra Ball. These aircraft provide the Air Force, joint warfighters, and national decision makers with unique and often sole-source Signals Intelligence, Measurement and Signature Intelligence, and Foreign Instrumentation Signals Intelligence across the range of military operations. Additionally, the Rivet Joint is the basis of a highly successful international cooperative program with the United Kingdom, through which combined United States Air Force and Royal Air Force (RAF) aircrews co-man Rivet Joint missions in support of their common intelligence requirements.

High-altitude ISR: In the FY 2017 budget request, the Air Force maintains planned U-2 aircraft divestment that begins in FY 2019 and is complete by FY 2020. This aligns U-2 divestiture with the anticipated fielding of enhanced RQ-4 Block 30 sensors. In accordance with congressional guidance, the Air Force is required to maintain the U-2 fleet in its current configuration and capability until the RQ-4 capabilities are equal to or greater than the U-2's capabilities, which is currently scheduled to occur in FY 2019. As a result, prudent investments are required to sustain U-2 operations and supply chain. The Air Force request includes Research and Development funding in FY 2017 to maintain U-2 fleet combat capability through planned divestiture. These funds address Diminishing Manufacturers' Source (DMS) issues in systems including datalink and Inertial Navigation Units/Global Positioning Systems.

Rapid Global Mobility

The FY 2017 budget request sustains intra-theater airlift capability by retiring 27 C-130H Hercules aircraft between FY 2017 and FY 2019, thus reducing excess capacity and freeing up funds to invest in the remaining fleet. This force restructure continues to allow the Air Force to support the defense strategy and direct support requirements. Finally, the Air Force balances enduring global air refueling requirements with capacity by retiring legacy aircraft as the KC-46 Pegasus tanker enters the operational fleet.

Airlift Compliance and Modernization: The FY 2017 budget request continues to fund extensive modernization efforts among tactical and strategic airlift aircraft. Under the C-130 Aircraft Modernization Program, Increment One (AMP-1), modification will continue in order to meet global Communications Navigation and Surveillance/Air Traffic Management (CNS/ATM) requirements. The Air Force expands upon AMP-1 improvements by funding the Aircraft Modernization Program, Increment Two (AMP-2), which adds Terrain Awareness and Warning System (TAWS), Flight Management System (FMS), and Multi-function Displays (MFD). The Air Force also funds the C-130 Center Wing Box replacement that will preclude the need to restrict aircraft due to exceeding flying hour limitations. Combined, these initiatives will ensure the longevity of the C-130 as a versatile tactical airlift platform. These enhancements are partially funded by the right-sizing of the tactical airlift fleet in line with OSD and Joint Staff requirement estimates.

Overview – FY 2017 Defense Budget

The budget request continues funding C-17 and C-5 avionics upgrades to bring them into compliance with federally-mandated air traffic control and communication standards. This is in addition to continued funding for fleet-wide survivability modifications through the Large Aircraft Infra-red Counter Measure (LAIRCM) system.

The FY 2017 budget funds the development and procurement of the Presidential Aircraft Recapitalization (PAR) program to replace the VC-25 Air Force One after FY 2020. This will enable the Air Force to continue delivering reliable, worldwide access with uncompromising security and connectivity for the President of the United States.

Tanker Replacement: Tanker recapitalization remains one of the Air Force's top three acquisition priorities, and the FY 2017 budget request continues to support the KC-46A Pegasus program. The KC-46 will perform multi-point refueling of joint and coalition aircraft and conduct aeromedical evacuation. It will also carry more cargo and/or passengers, while deploying with fewer external logistical support requirements, than the KC-135. The current program plan will deliver 85 aircraft by end of calendar year 2021 and procure a total of 179 KC-46 aircraft.

Special Operations: The FY 2017 budget request sustains ongoing efforts to recapitalize the Air Force Special Operations Command's (AFSOC) legacy fleet across the FYDP by increasing the AC-130J fleet to 32 aircraft and the MC-130J fleet to 47 aircraft. This will preserve the nation's ability to provide specialized air mobility and precision strike capabilities that have been in high demand for over a decade.

Global Strike

Nuclear Deterrence: Strengthening the nuclear enterprise remains one of the Air Force's highest priorities. The Air Force continues its actions to deliver safe, secure, and effective nuclear capabilities within its Nuclear Deterrence Operations (NDO) portfolio. The Air Force's intercontinental ballistic missiles and bombers provide two legs of the nation's Nuclear Triad and dual-capable fighters and bombers extend deterrence and provide assurance to our allies and partners.

Intercontinental Ballistic Missile (ICBM): The FY 2017 budget request funds additional investments to sustain and modernize the ICBM force, including Ground Based Strategic Deterrent (GBSD) integrated design and development.

Manpower Supporting the Nuclear Enterprise: The FY 2017 budget request centralizes the oversight and control of the nuclear enterprise by transferring ownership of Kirtland Air Force Base from Air Force Material Command (AFMC) to Air Force Global Strike Command (AFGSC) and transferring the B-1 bomber / Long Range Strike Bomber (LRS-B) mission from Air Combat Command (ACC) to AFGSC. These moves transferred over 8,600 military and civilian authorizations into AFGSC's oversight.

Nuclear Helicopter Support: The FY 2017 budget supports a replacement program for the Vietnam era UH-1N light-lift utility helicopter fleet to enhance the security provided to the Intercontinental Ballistic Missile (ICBM) inventory. The AFGSC is seeking to replace all UH-1N aircraft with commercial off-the-shelf/government off-the-shelf (COTS/GOTS) solutions to fill current capability gaps.

Legacy Dual-Capable Aircraft (DCA): The Air Force continues to modernize dual-capable fighter aircraft to support long-range interdiction capabilities.

Airborne Capabilities: The Air Force continues to modernize its bomber fleet to extend the life of the B-52 Stratofortress, B-1 Lancer, and B-2 Spirit aircraft. In FY 2017, the Air Force will continue the bomber modernization efforts and include additional investment for the B-52 Radar

Overview – FY 2017 Defense Budget

Modernization Program, B-2 EHF survivable communications, and Increment 2 of the Common Very Low Frequency/Low Frequency Receiver (CVR) program to develop a receive-only survivable communication path for future integration on bomber, tanker, and command and control aircraft. The FY 2017 budget request fully funds the B-2 Defensive Management Systems-Modernization (DMS-M) program to enable penetration of dense threat environments. The FY 2017 budget request also funds the B-2 Low Observable Signature and Supportability Modification (LOSSM).

United States Air Forces in Europe (USAFE) Weapons Storage and Security System (WS3) Modernization: The WS3 is the cornerstone of the North Atlantic Treaty Organization nuclear weapons security. A programmed SLEP is scheduled to replace unsustainable alarm and display equipment and ensure the system meets new National Security Agency (NSA) encryption standards. This effort meets additional requirements for USAFE and gains efficiencies by implementing modifications and configuration changes on the new alarm equipment during SLEP installations.

Long Range Strike Bomber (LRS-B): The LRS-B aircraft is also one of the Air Force's top three acquisition priorities and is currently in the development phase. The Air Force's FY 2017 budget request continues funding to develop the affordable, long range, penetrating aircraft that incorporates proven technologies to support the awarded contract. This bomber represents a key component to the joint portfolio of conventional and nuclear deep-strike capabilities.

B61-12 Tail Kit: The Air Force's FY 2017 budget continues funding for the B61-12 bomb Tail Kit Assembly. This program is a joint venture with the National Nuclear Security Administration's life extension program and combines four older variants into the B61-12. This investment will allow the Air Force to field a modernized weapon to meet operational requirements and provide nuclear assurance to U.S. allies in Europe.

Long Range Stand-Off (LRSO) Weapon: The FY 2017 budget maintains the Department's commitment to the LRSO program. The LRSO effort will develop a weapon system to replace the Air Launched Cruise Missile, which has been operational since 1986. The LRSO weapon system will be capable of penetrating and surviving advanced Integrated Air Defense Systems from significant stand-off ranges to prosecute strategic targets in support of the Air Force's nuclear deterrence operations core function.

Air Launched Cruise Missile (ALCM): The FY 2017 budget request continues funding for the procurement of the remaining ALCM Service Life Extension Program kits and additional kits required for attrition reserve. It also replaces and refurbishes critical non-nuclear components inside the ALCM to meet requirements for sustainment.

Command and Control (C2)

Command and Control: The FY 2017 budget request funds legacy Joint Surveillance and Target Attack Radar System (JSTARS) aircraft while recognizing that some aircraft are approaching the end of service life. The Air Force anticipates developing a fleet retirement plan informed by strategic assessments of capability requirements. Additionally, the Air Force added funding to preserve the Airborne Warning and Control System (AWACS) Reserve Association Group at Tinker Air Force Base, Oklahoma. This action increases near-term capacity to meet the highest-priority combatant commander requirements while preparing for future fights. The Air Force also continues to fund crews that will use legacy deployable Radar approach control (D-RAPCON) equipment as they wait to transition to new systems.

JSTARS Recapitalization: The FY 2017 budget request sustains the Air Force's commitment to command and control (C2) across the range of military operations. The budget request pursues C2 modernization critical to ensure a dominant C2 capability in current and future

Overview – FY 2017 Defense Budget

conflicts. The FY 2017 budget reflects an affordable acquisition strategy for JSTARS Recapitalization that is expected to reach initial operating capability by 2024.

AWACS Legacy: The budget request funds several upgrades to the AWACS fleet including Block 40/45 (mission systems), DRAGON (digital cockpit and navigation system), E-3 Radar electronic protection capability, next generation identification-friend-or-foe, and combat identification modifications.

E-4B National Airborne Operations Center (NAOC) Recapitalization: The FY 2017 budget request funds the initial Research, Development, Test and Evaluation profile for the NAOC recapitalization. This effort is a critical part of the NC3 modernization plan.

D-RAPCON: The FY 2017 budget request slows the procurement of the D-RAPCON system by procuring 10 of 15 systems in the FYDP.

Combat Survivor Evader Locator: The FY 2017 budget request funds cryptologic modifications. This effort ensures compliance with mandatory NSA cryptologic standards.

Core Mission Enablers

Military Construction (MILCON) and Facilities Sustainment, Restoration and Modernization (FSRM): The Air Force maintained facility sustainment at minimal levels, focused on investing its resources on the highest installation priorities, and increased MILCON investment. The Air Force increased its MILCON funding by 14.5 percent above the FY 2016 enacted levels to address shortfalls and an increased backlog that resulted from sequestration level funding. It also maintains the Military Family Housing construction program, with a focus on Okinawa.

The FY 2017 budget request for MILCON continues to support construction for combatant commands (e.g., U.S. European Command's Joint Intelligence Analysis Center), weapon system bed downs (e.g., F-35A, KC-46A, CRH), Asia-Pacific Resiliency, and "Quality-of-Life" (e.g., basic military training and fitness center). It also strengthens the prime mission priority within the Air Force, the nuclear enterprise, by constructing a new Consolidated Communications Facility, and renovates missile transfer as well as missile maintenance facilities. The Air Force intends to mitigate reduced FSRM investment levels by using an enterprise-wide approach to target resources to keep "good facilities good" and focus funding through a "mission critical, worst first" approach.

Personnel: In recent years, the Air Force sought to reduce near-term capacity to improve the readiness of the remaining force while sustaining key modernization efforts. Part of this strategy included the decision to drawdown active duty end strength levels from approximately 330 thousand in FY 2014 to a targeted level of roughly 309 thousand by FY 2017. However, the geopolitical situation (such as events surrounding the Islamic State of Iraq and the Levant (ISIL), Crimea, and Ukraine), coupled with force structure rephasing (A-10, EC-130, and other weapon systems retained), led to the assessment that the FY 2015 manpower profile projections were too low to support mission requirements. The FY 2016 budget began to address key capability gaps and grew end strength to address voids within the nuclear, maintenance, cyber, and ISR enterprises. While the FY 2017 budget request is fully funded at 317,000 end strength, the Air Force will continue its concerted effort to "right the force" by stabilizing the force size and assessing critical capabilities that may necessitate future military manpower growth. The FY 2017 budget request also continues to leverage the Guard and the Reserve.

Readiness: The Air Force continues to have significant readiness concerns. Readiness decreased in FY 2015 to historically low levels. The continued pressure of deployments and chronic shortage of Airmen in critical skill positions are limiting recovery efforts. Though very

Overview – FY 2017 Defense Budget

good at the current operations, less than 50 percent of Combat Air Forces are proficient in other required mission sets. Moreover, adversaries are closing the gap in military capability, the legacy force is less viable against advanced integrated air defense capabilities, and space is no longer a sanctuary. The Air Force recapitalization and modernization efforts will improve both capability and capacity in the long term. The FY 2017 budget request will improve key readiness building areas such as critical skills capacity and training infrastructure. With sustained improvements in the deploy-to-dwell ratio and predictable resource levels, the Air Force expects to improve readiness within 8 to 10 years.

Conclusion

The FY 2017 budget request represents a “pivot point” for the Air Force to continue the recovery to “balance the force” for today’s readiness and the readiness needed 10 to 20 years from now. However, FY 2017 could simply represent a pause to the devastating effects of sequestration level funding that will return in FY 2018. Without relief from sequestration, the Air Force will be forced to consider drastic actions, such as force structure and manpower reductions, reduced readiness, and cancellations and delays of key modernization programs. Operating at reduced funding levels since 2013 has resulted in an Air Force that is less ready, less capable, and less viable than the one America demands. Operating at sequestration level funding in the future will only amplify known capacity, capability, and readiness shortfalls.

The Air Force’s FY 2017 budget request maintains the delicate balance between capability, capacity, and readiness. Informed by current geopolitical conditions and ongoing operations, this budget also restores capacity and makes additional investments in nuclear, space, cyber, ISR, and command and control capabilities. Finally, this budget funds the Air Force’s greatest asset, the nation’s Airmen, by restoring critical active duty manpower billets.

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9. PERFORMANCE IMPROVEMENT

INTRODUCTION

Purpose

This chapter satisfies the requirements of the Government Performance and Results Act of 1993 (GPRA), the GPRA Modernization Act (GPRAMA) of 2010, and Office of Management and Budget (OMB) Circular A-11 — which call for integration of annual performance goals and results with congressional budget justifications. This chapter complements the appropriation-specific budget justification information that is submitted to Congress by providing:

- A performance-focused articulation of the Department's strategic goals and objectives; and
- A limited number of Department-wide performance improvement priorities for senior level management attention in the current and budget year.

The Department looks forward to working with the Administration and Congress to meet the challenge of creating more effective and efficient operations while delivering a high-value return for the American taxpayer's investment in the Defense Department.

DoD Performance Plan and Report

The FY 2015 DoD Annual Performance Report (APR) provides a summary of the Department's prior year performance results. This chapter presents an excerpt from the full report, available at: <http://dcmo.defense.gov/Publications/AnnualPerformancePlanandPerformanceReport.aspx>. The FY 2015-2018 Agency Strategic Plan (ASP)/Annual Performance Plan (APP) outlines the Department's strategic goals, strategic objectives, and performance goals, available at: <http://dcmo.defense.gov/Publications/DoDASP.aspx>.

FY 2015 DOD ANNUAL PERFORMANCE REPORT

Executive Summary

The FY 2015 APR is intended to inform the general public about the Department's progress towards achieving the 44 enterprise-wide performance goals described in the Agency Strategic Plan for Fiscal Years 2015-2018.

Far more than 44 performance measures would be needed to fully capture the breadth and scope of the Department's world-wide responsibilities, or even the Department's management efforts. Indeed, the Department uses dozens of performance measures to assess its progress in each of many key areas such as acquisition performance, military readiness, audit readiness, and the health of the force. Moreover, significant efforts in areas such as the readiness of the force cannot be fully represented in this or future public performance reports due to the sensitivity of the information involved. While the Department endeavors to improve its Agency Strategic Plan and Performance Report over time, these reports necessarily represent only a partial picture of DoD's management efforts, and management progress.

The measures included in this report show that the Department maintained solid performance in supporting the operational force in the field while reducing unnecessary overhead. In the area of human resources, transition support to veterans remained good and the quality of recruits remained high. However, due to budget restrictions, the Department did not achieve all its goals for improving quality of family housing and is falling slightly short in acquisition qualifications and hiring timelines. These areas will continue to be a major focus of future

Overview – FY 2017 Defense Budget

agency strategic plans. Further, the goal of achieving Department-wide financial auditability shows poor progress. However, the Under Secretary of Defense (Comptroller) and the Defense Chief Management Officer (DCMO) have worked with the Military Departments and Defense Agencies to develop an aggressive new plan to put the Department on a sound track toward future audit readiness.

The Department also undertook significant management improvements that are not fully reflected in the performance measures included in the Agency Strategic Plan or in this report. For example:

- During FY 2015, Secretary Carter directed and the OSD carried out the Force of the Future initiative, which a major review of human capital strategy. This review put fundamental emphasis on changing how the Department manages both military and civilian personnel and how it considers new skill sets required to meet future needs. The Under Secretary of Defense for Personnel and Readiness developed a number of performance measures to assess the implementation of the Force of the Future initiative.
- In the area of innovation and technical excellence, the Department is carrying out a Better Buying Power initiative that appears to have significantly improved acquisition performance. The next phase of the Better Buying Power initiative is now being rolled out. With it comes an emphasis on taking more advantage of the technical innovation within private industry. The Under Secretary of Defense for Acquisition, Technology, and Logistics is tracking a number of performance measures to assess the implementation of the Better Buying Power initiative.
- In the area of cyber security, the Department has undertaken significant new efforts to address challenges associated with ongoing cyber threats. The Chief Information Officer of the Department of Defense has developed a Cybersecurity scorecard to track the implementation of a number of key initiatives in the cyber arena.

During FY 2015, the DCMO team led a Department-wide effort to identify concrete, measurable management reforms in areas such as Department-wide retail sales; reduction in the size of major headquarters; reduction in the number and cost of advisory and assistance contracts; and efficiencies in the provision of information technology support to the Department. This collective effort is aimed at generating over \$6 billion in savings that can be reallocated to higher priority needs such as new mission equipment investment or training and readiness of combat forces.

FY 2015 Agency Priority Goal (APG) Results

Pursuant to the GPRA Modernization Act of 2010, the Department established four APGs for FY 2014 and FY 2015 that were used to track the Department's progress toward achieving priorities throughout FY 2015.

The annual results and detailed narratives may be found in the "Summary of DoD Performance by Strategic Objective" section.

Please refer to performance.gov for the Department's contributions to the APGs and its progress.

Cross-Agency Priority Goals

Title 31 of the U.S. Code § 1116 requires the identification of Cross-Agency Priority (CAP) Goals in areas where increased cross-agency coordination on outcome-focused areas is likely to improve progress. Please refer to www.Performance.gov for the Department's contributions to these goals. The DoD, in partnership with OMB, currently leads the CAP Goals for Cybersecurity and Strategic Sourcing. In addition, DoD contributes to the following CAP Goals:

- Insider Threat and Security Clearance

Overview – FY 2017 Defense Budget

- Service Members and Veterans Mental Health
- People and Culture
- Benchmarking
- Infrastructure Permitting and Modernization
- STEM Education
- Lab-to-Market
- Smarter IT Delivery
- Open Data
- Climate Change – Federal Actions
- Shared Services

High Risk Areas

To drive increased accountability and efficiencies in the Federal government, the Government Accountability Office (GAO) determines high risk areas across the Federal government based on vulnerability to fraud, waste, abuse, or mismanagement, and changes required to address major economic, efficiency, or effectiveness challenges. The GAO has published the biennial high-risk series updates since 1990 (see <http://www.gao.gov/highrisk/overview>). The Department shares responsibility for the following cross-agency areas on the GAO high risk list:

- DoD Approach to Business Transformation
- DoD Business Systems Modernization
- DoD Support Infrastructure
- DoD Financial Management
- DoD Supply Chain Management
- DoD Weapon System Acquisition
- DoD Contract Management
- Strategic Human Capital Management
- Limiting Federal Government Fiscal Exposure by Better Managing Climate Change Risk
- Ensuring the Security of Federal Information Systems and Cyber Critical Infrastructure and Protecting the Privacy of PII
- Establishing Effective Mechanisms for sharing and Managing Terrorism Related Information to Protect the Homeland
- Managing Federal Real Property
- Mitigating Gaps in Weather Satellite Data
- Ensuring Effective Protection of Technologies Critical US National Security Interests
- Improving and Modernizing Federal Disability Programs
- Improving the Management of IT Acquisitions
- Managing Risks and Improving VA Health Care

DoD Major Management Challenges

The Office of the Inspector General (IG) works to promote efficiency, effectiveness, and integrity in the programs and operations of the Department. The DoD IG identified the following areas as presenting the most serious management and performance challenges:

- Financial Management
- Acquisition Processes and Contract Management
- Joint Warfighting and Readiness
- Cyber Security
- Health Care
- Equipping and Training Iraq and Afghan Security Forces
- The Nuclear Enterprise

Detailed information regarding these challenges, the IG's assessment of the Department's progress, and the Department's management response can be found with the report at <http://dodig.mil>

APPENDIX A: RESOURCE EXHIBITS

Table A-1. Combat Force Structure Overview

Service	FY 2016	FY 2017	Delta FY16- FY17
Army Active			
Brigade Combat Teams (BCT)	30	30	-
Combat Aviation Brigades (CAB)	11	11	-
Army National Guard			
BCT	28	26	-2
CAB/Aviation Restructure Initiative	8	8	-
Army Reserve			
CAB/Theater Aviation Brigade	2	2	-
Navy			
Number of Ships	280	287	+7
Carrier Strike Groups	11	11	-
Marine Corps Active			
Marine Expeditionary Forces	3	3	-
Infantry Battalions	24	24	-
Marine Corps Reserve			
Marine Expeditionary Forces	-	-	-
Infantry Battalions	8	8	-
Air Force Active			
Combat Coded Squadrons	40	41	+1
Aircraft Inventory (TAI)	4,031	4,056	+25
Air Force Reserve			
Combat Coded Squadrons	3	3	-
Aircraft Inventory (TAI)	332	326	-6
Air National Guard			
Combat Coded Squadrons	21	20	-1
Aircraft Inventory (TAI)	1,093	1,090	-3

Overview – FY 2017 Defense Budget

Table A-2. Active Component End Strength (in Thousands)

Service	FY 2016 Estimate ^{1/}	FY 2017	Delta FY16 - FY17
Army	475.0	460.0	-15.0
Navy	327.3	322.9	-4.4
Marine Corps	182.0	182.0	--
Air Force	317.0	317.0	--
TOTAL^{2/}	1,301.3	1,281.9	-19.4

Numbers may not add due to rounding

^{1/} Projected end strength.

^{2/} President's invoking of emergency authorities permits end strength to vary from authorized levels

Table A-3. Reserve Component End Strength (in Thousands)

Service	FY 2016 Estimate ^{1/}	FY 2017	Delta FY16 - FY17
Army Reserve	198.0	195.0	-3.0
Navy Reserve	57.4	58.0	+0.6
Marine Corps Reserve	38.9	38.5	-0.4
Air Force Reserve	69.2	69.0	-0.2
Army National Guard	342.0	335.0	-7.0
Air National Guard	105.5	105.7	+0.2
TOTAL	811.0	801.2	-9.8

Numbers may not add due to rounding

^{1/} Projected end strengths.

Table A-4. DoD Base Budget by Appropriation Title

<i>\$ in Thousands</i> Base Budget	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	135,330,213	135,269,240	-60,973
Operation and Maintenance	197,468,777	205,860,227	+8,391,450
Procurement	110,737,432	102,566,680	-8,170,752
RDT&E	68,778,330	71,391,771	+2,613,441
Revolving and Management Funds	1,175,932	1,371,613	+195,681
Defense Bill	513,490,684	516,459,531	+2,968,847
Military Construction	6,909,712	6,124,204	-785,508
Family Housing	1,261,288	1,319,852	+58,564
Military Construction Bill	8,171,000	7,444,056	-726,944
Total	521,661,684	523,903,587	+2,241,903

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

Overview – FY 2017 Defense Budget

Table A-5. DoD Base Budget by Military Department

<i>\$ in Thousands</i> Base Budget	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Army	123,259,240	122,998,058	-261,182
Navy	159,337,556	155,384,640	-3,952,916
Air Force	145,685,330	151,052,826	+5,367,496
Defense-Wide	93,379,558	94,468,063	+1,088,505
Total	521,661,684	523,903,587	+2,241,903

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

Table A-6. DoD OCO Budget by Appropriation Title

<i>\$ in Thousands</i> OCO Budget	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	3,222,673	3,562,258	+339,585
Operation and Maintenance	46,966,155	45,034,083	-1,932,072
Procurement	8,128,888	9,514,408	+1,385,520
RDT&E	231,434	374,169	+142,735
Revolving and Management Funds	88,850	140,633	+51,783
Defense Bill	58,638,000	58,625,551	-12,449
Military Construction	--	172,449	+172,449
Family Housing	--	--	--
Military Construction Bill	--	172,449	+172,449
Total	58,638,000	58,798,000	+160,000

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

Table A-7. DoD OCO Budget by Military Department

<i>\$ in Thousands</i> OCO Budget	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Army	23,668,804	25,035,892	+1,367,088
Navy	9,449,242	9,476,438	+27,196
Air Force	16,098,000	15,826,413	-271,587
Defense-Wide	9,421,954	8,459,257	-962,697
Total	58,638,000	58,798,000	+160,000

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

Overview – FY 2017 Defense Budget

Table A-8. DoD Total Budget by Appropriation Title

<i>\$ in Thousands</i> Total Budget	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	138,552,886	138,831,498	+278,612
Operation and Maintenance	244,434,932	250,894,310	+6,459,378
Procurement	118,866,320	112,081,088	-6,785,232
RDT&E	69,009,764	71,765,940	+2,756,176
Revolving and Management Funds	1,264,782	1,512,246	+247,464
Defense Bill	572,128,684	575,085,082	+2,956,398
Military Construction	6,909,712	6,296,653	-613,059
Family Housing	1,261,288	1,319,852	+58,564
Military Construction Bill	8,171,000	7,616,505	-554,495
Total	580,299,684	582,701,587	+2,401,903

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

Table A-9. DoD Total Budget by Military Department

<i>\$ in Thousands</i> Total Budget	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Army	146,928,044	148,033,950	+1,105,906
Navy	168,786,798	164,861,078	-3,925,720
Air Force	161,783,330	166,879,239	+5,095,909
Defense-Wide	102,801,512	102,927,320	+125,808
Total	580,299,684	582,701,587	+2,401,903

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

Table A-10. DoD Base Budget by Military Department and Appropriation Title

<i>\$ in Thousands</i> Department of the Army	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	56,156,215	55,225,375	-930,840
Operation and Maintenance	40,829,451	43,516,908	+2,687,457
Procurement	16,971,233	15,338,059	-1,633,174
RDT&E	7,552,871	7,515,399	-37,472
Military Construction	1,107,725	819,118	-288,607
Family Housing	446,313	526,730	+80,417
Revolving and Management Funds	195,432	56,469	-138,963
Total Department of the Army	123,259,240	122,998,058	-261,182

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

Overview – FY 2017 Defense Budget

<i>\$ in Thousands</i> Department of the Navy	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	45,281,913	45,555,508	+273,595
Operation and Maintenance	45,978,052	46,917,890	+939,838
Procurement	47,441,469	44,039,282	-3,402,187
RDT&E	17,882,860	17,276,301	-606,559
Military Construction	1,909,521	1,200,733	-708,788
Family Housing	369,577	394,926	+25,349
Revolving and Management Funds	474,164	--	-474,164
Total Department of the Navy	159,337,556	155,384,640	-3,952,916

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

<i>\$ in Thousands</i> Department of the Air Force	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	33,892,085	34,488,357	+596,272
Operation and Maintenance	44,111,454	47,661,084	+3,549,630
Procurement	41,002,607	38,521,056	-2,481,551
RDT&E	24,475,957	28,112,251	+3,636,294
Military Construction	1,648,599	1,870,330	+221,731
Family Housing	491,730	335,781	-155,949
Revolving and Management Funds	62,898	63,967	+1,069
Total Department of the Air Force	145,685,330	151,052,826	+5,367,496

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

<i>\$ in Thousands</i> Defense-Wide	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	--	--	--
Operation and Maintenance	66,549,820	67,764,345	+1,214,525
Procurement	5,322,123	4,668,283	-653,840
RDT&E	18,866,642	18,487,820	-378,822
Military Construction	2,243,867	2,234,023	-9,844
Family Housing*	-46,332	62,415	+108,747
Revolving and Management Funds	443,438	1,251,177	+807,739
Total Defense-Wide	93,379,558	94,468,063	+1,088,505

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

Grand Total Budget	521,661,684	523,903,587	+2,241,903

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

* Negative in FY 2016 due to a rescission in the Homeowner's Assistance Fund that exceeded the total appropriated amount for Defense-Wide in the Family Housing public law title.

Overview – FY 2017 Defense Budget

Table A-11. DoD OCO Budget by Military Department and Appropriation Title

<i>\$ in Thousands</i> Department of the Army	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	2,036,833	2,290,556	+253,723
Operation and Maintenance	19,197,494	19,805,016	+607,522
Procurement	2,432,977	2,774,065	+341,088
RDT&E	1,500	100,522	+99,022
Military Construction	--	18,900	+18,900
Family Housing	--	--	--
Revolving and Management Funds	--	46,833	+46,833
Total Department of the Army	23,668,804	25,035,892	+1,367,088

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

<i>\$ in Thousands</i> Department of the Navy	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	438,176	525,983	+87,807
Operation and Maintenance	8,577,243	8,101,319	-475,924
Procurement	398,076	711,004	+312,928
RDT&E	35,747	78,323	+42,576
Military Construction	--	59,809	+59,809
Family Housing	--	--	--
Revolving and Management Funds	--	--	--
Total Department of the Navy	9,449,242	9,476,438	+27,196

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

<i>\$ in Thousands</i> Department of the Air Force	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	747,664	745,719	-1,945
Operation and Maintenance	11,206,819	9,576,416	-1,630,403
Procurement	4,123,917	5,382,633	+1,258,716
RDT&E	17,100	32,905	+15,805
Military Construction	--	88,740	+88,740
Family Housing	--	--	--
Revolving and Management Funds	2,500	--	-2,500
Total Department of the Air Force	16,098,000	15,826,413	-271,587

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

Overview – FY 2017 Defense Budget

<i>\$ in Thousands</i> Defense-Wide	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	--	--	--
Operation and Maintenance	7,984,599	7,551,332	-433,267
Procurement	1,173,918	646,706	-527,212
RDT&E	177,087	162,419	-14,668
Military Construction	--	5,000	+5,000
Family Housing	--	--	--
Revolving and Management Funds	86,350	93,800	+7,450
Total Defense-Wide	9,421,954	8,459,257	-962,697

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

Grand Total Budget	58,638,000	58,798,000	+160,000

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

Table A-12. DoD Total Budget by Military Department and Appropriation Title

<i>\$ in Thousands</i> Department of the Army	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	58,193,048	57,515,931	-677,117
Operation and Maintenance	60,026,945	63,321,924	+3,294,979
Procurement	19,404,210	18,112,124	-1,292,086
RDT&E	7,554,371	7,615,921	+61,550
Military Construction	1,107,725	838,018	-269,707
Family Housing	446,313	526,730	+80,417
Revolving and Management Funds	195,432	103,302	-92,130
Total Department of the Army	146,928,044	148,033,950	+1,105,906

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

<i>\$ in Thousands</i> Department of the Navy	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	45,720,089	46,081,491	+361,402
Operation and Maintenance	54,555,295	55,019,209	+463,914
Procurement	47,839,545	44,750,286	-3,089,259
RDT&E	17,918,607	17,354,624	-563,983
Military Construction	1,909,521	1,260,542	-648,979
Family Housing	369,577	394,926	+25,349
Revolving and Management Funds	474,164	--	-474,164
Total Department of the Navy	168,786,798	164,861,078	-3,925,720

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

Overview – FY 2017 Defense Budget

<i>\$ in Thousands</i> Department of the Air Force	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	34,639,749	35,234,076	+594,327
Operation and Maintenance	55,318,273	57,237,500	+1,919,227
Procurement	45,126,524	43,903,689	-1,222,835
RDT&E	24,493,057	28,145,156	+3,652,099
Military Construction	1,648,599	1,959,070	+310,471
Family Housing	491,730	335,781	-155,949
Revolving and Management Funds	65,398	63,967	-1,431
Total Department of the Air Force	161,783,330	166,879,239	+5,095,909

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

<i>\$ in Thousands</i> Defense-Wide	FY 2016 Enacted	FY 2017 Request	Delta FY17 - FY16
Military Personnel	--	--	--
Operation and Maintenance	74,534,419	75,315,677	+781,258
Procurement	6,496,041	5,314,989	-1,181,052
RDT&E	19,043,729	18,650,239	-393,490
Military Construction	2,243,867	2,239,023	-4,844
Family Housing	-46,332	62,415	+108,747
Revolving and Management Funds	529,788	1,344,977	+815,189
Total Defense-Wide	102,801,512	102,927,320	+125,808

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

Grand Total Budget	580,299,684	582,701,587	+2,401,903

Note: Reflects Discretionary Budget Authority

Numbers may not add due to rounding

APPENDIX B: Acronym List

NOTE: This is not a comprehensive list of all acronyms used in the Overview.

Acronym	Definition
AC	Active Component
ACC	Air Combat Command
AD	Area Denial
ADCP	Advanced Display Core Processor
ADS-B	Automatic Dependent Surveillance-Broadcast
AEHF	Advanced Extremely-High Frequency
AESA	Active Electronically Scanned Array
AFGSC	Air Force Global Strike Command
AFMC	Air Force Material Command
AFSOC	Air Force Special Operations Command
AGM	Advanced Guided Missile
AH	Apache Helicopter
AIM	Air Intercept Missile
ALCM	Air Launched Cruise Missile
AMP	Aircraft Modernization Program
AMPV	Armored Multi-Purpose Vehicle
AMRAAM	Advanced Medium Range Air-to-Air Missile
ANA	Afghanistan National Army
ANP	Afghanistan National Police
ANDSF	Afghan National Defense and Security Forces
AORs	Areas of Responsibility
APG	Agency Priority Goal
APP	Annual Performance Plan
APS	Army Pre-Positioned Stocks
ARI	Aviation Restructuring Initiative
ARNG	Army Reserve/National Guard
ASD	Assistant Secretary of Defense
ASD/HA	Assistant Secretary of Defense for Health Affairs
ASFF	Afghanistan Security Forces Fund
ASP	Agency Strategic Plan
AWACS	Airborne Warning and Control System
BA	Budget Authority
BAH	Basic Allowance for Housing
BAS	Basic Allowance for Subsistence
BBA	Bipartisan Budget Act of 2013
BBP	Better Buying Power
BCA	Budget Control Act of 2011
BMD	Ballistic Missile Defense
BRAC	Base Realignment and Closure

Overview – FY 2017 Defense Budget

BSRF	Black Sea Rotational Force
CAF	Combat Air Forces
CANES	Consolidated Afloat Networks and Enterprise Services
CAP	Cross-Agency Priority
CENTCOM	Central Command
CERP	Commanders Emergency Response Program
CH	Chinook helicopter
CNS/ATM	Communications Navigation and Surveillance/Air Traffic Management
COD	Carrier Onboard Delivery
COLA	Cost-Of-Living Allocation
CONUS	Contiguous United States
COTS/GOTS	Commercial Off-The-Shelf/Government Off-The-Shelf
CRH	Combat Rescue Helicopter
CSA	Chief of Staff of the Army
CSA	Critical Skills Availability
CSG	Carrier Strike Group
CT	Counterterrorism
CTC	Combat Training Center
CTPF	Counterterrorism Partnerships Fund
CV	Carrier Variant
CVN	aircraft carrier, fixed wing, nuclear powered
CVR	Common Very Low Frequency
CWMD	Chemical Weapons of Mass Destruction
DA	Decisive Action
DAWDF	Defense Acquisition Workforce Development Fund
DAWIA	Defense Acquisition Workforce Improvement Act
DCA	Dual-Capable Aircraft
DCAA	Defense Contract Audit Agency
DCMA	Defense Contract Management Agency
DCO	Defensive Cyberspace Operations
DCMO	Defense Chief Management Officer
DHA	Defense Health Agency
DHP	Defense Health Program
DII	Defense Innovation Initiative
DIU	Defense Innovation Unit
DLIFLC	Defense Language Institute Foreign Language Center
DME	Durable Medical Equipment
DMS	Defensive Management Systems
DMS	Diminishing Manufacturers' Source
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
DoDEA	Department of Defense Education Activity
DoD IG	Department of Defense Office of the Inspector General
DoDIN Ops	DoD Information Network Operations

Overview – FY 2017 Defense Budget

DoN	Department of the Navy
DOPMA	Defense Officer Personnel Management
D-RAPCOM	Deployable Radar Approach Control
DTRA	Defense Threat Reduction Agency
ECI	Employment Cost Index
EELV	Evolved Expendable Launch Vehicle
EPAA	European Phased Adaptive Approach
EPAWSS	Eagle Passive/Active Warning Survivability System
ERI	European Reassurance Initiatives
FCP	Federal Ceiling Price
FERS	Federal Employees Retirement System
FHP	Flying Hour Program
FIAR	Financial Improvement and Audit Readiness
FM	Financial Management
FMS	Flight Management System
FNH	Foreign National Indirect Hire
FSRM	Facilities Sustainment, Restoration and Modernization
FY	Fiscal Year
FYDP	Future Years Defense Program
GAO	Government Accountability Office
GBI	Ground-Based Interceptors
GBSD	Ground Based Strategic Deterrent
GBU	Guided Bomb Unit
GCC	Geographic Combatant Commands
GMD	Ground-based Midcourse Defense
GO	Global Officer
GO/FO	General Officer/Flag Officer
GIO	Globally Integrated Operations
GPF	General Purpose Forces
GPRA	Government Performance and Results Act of 1993
GPRAMA	GPRA Modernization Act of 2010
GPS	Global Positioning System
GRP	Gross Retired Pay
GT	Global Thunder
HC	Combat King Helicopter
HH	Combat Rescue Helicopter
HMO	health maintenance organization
HRET	Health Research & Educational Trust
HQ	Headquarter
IBCT	Infantry Brigade Combat Team
ICBM	Intercontinental Ballistic Missile
IED	Improvised Explosive Device
IG	Inspector General
IPA	Independent Public Accountant

Overview – FY 2017 Defense Budget

ISF	Iraqi Security Forces
ISIL	Islamic State in Iraq and the Levant
ISR	Intelligence, Surveillance, and Reconnaissance
IT	Information Technology
ITEF	Iraq Train and Equip Fund
ITX	Integrated Training Exercise
JADGE	Japan Aerospace Defense Ground Environment
JASSM-ER	Joint Air-to-Surface Standoff Missile-Extended Range
JCET	Joint Combined Exchange Training
JIDA	Joint Improvised-Threat Defeat Agency
JIE	Joint Information Environment
JLTV	Joint Light Tactical Vehicle
JSF	Joint Strike Fighter
JSTARS	Joint Surveillance Target Attack Radar System
JTCP	Joint Training Coordination Program
JTEN	Joint Training Enterprise Network
KFF	Kaiser Family Foundation
KV	Kill Vehicle
LAIRCM	Large Aircraft Infra-red Counter Measure
LCS	Littoral Combat Ship
LHA	Landing Helicopter Assault
LOSSM	Low Observable Signature and Supportability Modification
LPD	Landing Platform Dock
LRDR	Long Range Discriminating Radar
LRS	Long Range Strike
LRS-B	Long Range Strike-Bomber
LRSO	Long Range Stand-Off
LTC	Language Training Centers
LVC	Live, Virtual, and Construct
MARSOC	Marine Forces Special Operations Command
MCRMC	Military Compensation and Retirement Modernization Commission
MEB	Marine Expeditionary Brigade
MEU	Marine Expeditionary Unit
MFD	Multi-function Displays
MGUE	Military GPS User Equipment
MH	Mission Helicopter
MHA	Major DoD Headquarters Activities
MHS	Military Health System
MILCON	Military Construction
MRAP	Mine-Resistant Ambush Protected
MRE	Mission Rehearsal Exercises
MSE	Missile Segment Enhancement
MSO/VSO	Military and Veteran Service Organizations
MTF	Military Treatment Facility

Overview – FY 2017 Defense Budget

MWR	Morale, Welfare, and Recreation
NAOC	National Airborne Command Center
NSA	National Security Agency
NATO	North Atlantic Treaty Organization
NDAA	National Defense Authorization Act
NGEN	Next Generation Enterprise Network
NHE	National Health Expenditure
NMS	National Military Strategy
NORAD	North American Aerospace Defense Command
NSS	National Security Strategy
NSWC	Naval Special Warfare Command
OCO	Overseas Contingency Operations
OCX	Operational Control System
ODO	Other Defense Agency
OFP	Operational Flight Program
OFRP	Optimized Fleet Response Plan
OFS	Operation Freedom's Sentinel
OIG	Office of the Inspector General
OIR	Operation Inherent Resolve
OMB	Office of Management and Budget
OPFOR	Opposing Forces
OPLAN	Operational Plans
OPIR	Overhead Persistent Infrared
OPTAR	Operating Target
ORT	Operation Rolling Tide
OSC-I	Office of Security Cooperation - Iraq
OSD	Office of the Secretary of Defense
OT	Occupational Therapy
OUSDC	Office of the Under Secretary of Defense (Comptroller)
OUSDP&R	Office of the Under Secretary of Defense (Personnel and Readiness)
PAC-3	Patriot Advanced Capability-3
PAR	Presidential Aircraft Recapitalization
PB 2014	President's Budget 2017
PCS	Permanent change of station
PII	Personally Identifiable Information
POA	Period Of Availability
POS	Point of Service
PPV	Public-Private Ventures
PR	Personnel Recovery
PSP	Precision Strike Package
PT	Physical Therapy
QDR	Quadrennial Defense Review
QRMC	Quadrennial Review of Military Compensation
RAF	Royal Air Force

Overview – FY 2017 Defense Budget

RAF	Regionally Aligned Forces
RC	Reserve Components
RD&A	Research Development and Acquisition
RDT&E	Research, Development, Test, and Evaluation
REKV	Redesigned Exo-atmospheric Kill Vehicle
RMC	Regular Military Compensation
ROK	Republic of Korea
ROTC	Reserve Officer Training Corps
RPA	Remotely Piloted Aircraft
SA	Secretary of the Army
S&I	Special and Incentive
S&T	Science and Technology
SATCOM	Satellite Communication
SBA	Schedule of Budgetary Activity
SBEM	Space Based Environmental Monitoring
SBIRS	Space Based Infrared System
SBR	Statements of Budgetary Resources
SBSS	Space-Based Space Surveillance
SCP	Service Cost Position
SDB II	Small Diameter Bomb Increment II
SHARP	Sexual Harassment/Assault Response & Prevention
SKR	Silent Knight Radar
SLEP	Service Life Extension Program
SM-3	Standard Missile-3
SOCAFRICA	Special Operations Command, AFRICOM
SOF	Special Operations Forces
SOF-P	SOF-Peculiar
SOPGM	Standoff Precision Guided Munitions
SPMAGTF	Special Purpose Marine Air Ground Task Force
SPMAGTF-CR	SPMAGTF Crisis Response
SPMAGTF-CR-AF	SPMAGTF-CR-Africa
SPMAGTF-CR-CC	SPMAGTF-CR-Central Command
SSA	Space Situational Awareness
SSBN	Submersible, Ballistic, Nuclear (submarine)
SSN	Submarine Nuclear
STEF	Syria Train and Equip Fund
STEM	Science, Technology, Engineering and Mathematics
STOVL	Short Take Off and Vertical Landing
SV	Space Vehicle
T-AO(X)	Transport Oiler (Next Generation)
TAI	Total Active Inventory
TAWS	Terrain Awareness and Warning System
TC	Turbo Challenge
TF/TA	Terrain Following/Terrain Avoidance

Overview – FY 2017 Defense Budget

TFCA	Task Force Cyber Awakening
TFL	TRICARE-for-Life
THAAD	Terminal High-Altitude Area
TRA	Training Resources Availability
TRJE	Trident Juncture
TSP	Thrift Savings Plan
TWCF	Transportation Working Capital Fund
UDP	Unit Deployment Program
UH	Utility Helicopter
ULO	Unified Land Operations
U.S.	United States
USAFRICOM	United States Africa Command
USAFE	United States Air Forces in Europe
USAR	United States Army Reserve
USASOC	United States Army Operations Command
USCENTCOM	United States Central Command
USCYBERCOM	United States Cyber Command
USEUCOM	U.S. European Command
USFHP	Uniformed Services Family Health Plans
UG	Ultimate Guardian
USNORTHCOM	U.S. Northern Command
USPACOM	United States Pacific Command
USSOCOM	United States Special Operations Command
USSOUTHCOM	United States Southern Command
USSTRATCOM	United States Strategic Command
USTRANSCOM	United States Transportation Command
VA	Department of Veterans Affairs
VSO	Vetted Syrian Opposition
WIN-T	Warfighter Information Network – Tactical
WS3	Weapons Storage and Security System
WSF	Weather System Follow-On
WSS	Weapons System Sustainment
YOS	Year of Service

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**Department of Defense
Fiscal Year (FY) 2017 President's Budget Submission**

February 2016



Defense Advanced Research Projects Agency

Defense-Wide Justification Book Volume 1 of 1

Research, Development, Test & Evaluation, Defense-Wide

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Table of Volumes

Defense Advanced Research Projects Agency.....	Volume 1
Missile Defense Agency.....	Volume 2
Office of the Secretary Of Defense.....	Volume 3
Chemical and Biological Defense Program.....	Volume 4
Defense Contract Management Agency.....	Volume 5
DoD Human Resources Activity.....	Volume 5
Defense Information Systems Agency.....	Volume 5
Defense Logistics Agency.....	Volume 5
Defense Security Cooperation Agency.....	Volume 5
Defense Security Service.....	Volume 5
Defense Technical Information Center.....	Volume 5
Defense Threat Reduction Agency.....	Volume 5
The Joint Staff.....	Volume 5
United States Special Operations Command.....	Volume 5
Washington Headquarters Service.....	Volume 5
Operational Test and Evaluation, Defense.....	Volume 5

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Defense Geospatial Intelligence Agency..... (see NIP and MIP Justification Books)

Defense Intelligence Agency..... (see NIP and MIP Justification Books)

National Security Agency.....(see NIP and MIP Justification Books)

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Volume 1 Table of Contents

Comptroller Exhibit R-1..... Volume 1 - v

Program Element Table of Contents (by Budget Activity then Line Item Number).....Volume 1 - xiii

Program Element Table of Contents (Alphabetically by Program Element Title).....Volume 1 - xv

Exhibit R-2's..... Volume 1 - 1

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Department of Defense
FY 2017 President's Budget
Exhibit R-1 FY 2017 President's Budget
Total Obligational Authority
(Dollars in Thousands)

08 Jan 2016

Appropriation -----	FY 2015 (Base & OCO)	FY 2016 Base Enacted	FY 2016 OCO Enacted	FY 2016 Total Enacted	FY 2017 Base	FY 2017 OCO	FY 2017 Total
-----	-----	-----	-----	-----	-----	-----	-----
Research, Development, Test & Eval, DW	2,915,932	2,868,281		2,868,281	2,973,036		2,973,036
Total Research, Development, Test & Evaluation	2,915,932	2,868,281		2,868,281	2,973,036		2,973,036

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Department of Defense
FY 2017 President's Budget
Exhibit R-1 FY 2017 President's Budget
Total Obligational Authority
(Dollars in Thousands)

08 Jan 2016

Summary Recap of Budget Activities -----	FY 2015 (Base & OCO)	FY 2016 Base Enacted	FY 2016 OCO Enacted	FY 2016 Total Enacted	FY 2017 Base	FY 2017 OCO	FY 2017 Total
-----	-----	-----	-----	-----	-----	-----	-----
Basic Research	381,371	389,663		389,663	420,088		420,088
Applied Research	1,136,845	1,163,380		1,163,380	1,246,308		1,246,308
Advanced Technology Development	1,241,088	1,243,667		1,243,667	1,232,637		1,232,637
Management Support	156,628	71,571		71,571	74,003		74,003
Total Research, Development, Test & Evaluation	2,915,932	2,868,281		2,868,281	2,973,036		2,973,036
 Summary Recap of FYDP Programs -----							
Research and Development	2,915,932	2,868,281		2,868,281	2,973,036		2,973,036
Total Research, Development, Test & Evaluation	2,915,932	2,868,281		2,868,281	2,973,036		2,973,036

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Defense-Wide
 FY 2017 President's Budget
 Exhibit R-1 FY 2017 President's Budget
 Total Obligational Authority
 (Dollars in Thousands)

08 Jan 2016

	FY 2015 (Base & OCO)	FY 2016 Base Enacted	FY 2016 OCO Enacted	FY 2016 Total Enacted	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Summary Recap of Budget Activities							

Basic Research	381,371	389,663		389,663	420,088		420,088
Applied Research	1,136,845	1,163,380		1,163,380	1,246,308		1,246,308
Advanced Technology Development	1,241,088	1,243,667		1,243,667	1,232,637		1,232,637
Management Support	156,628	71,571		71,571	74,003		74,003
Total Research, Development, Test & Evaluation	2,915,932	2,868,281		2,868,281	2,973,036		2,973,036
Summary Recap of FYDP Programs							

Research and Development	2,915,932	2,868,281		2,868,281	2,973,036		2,973,036
Total Research, Development, Test & Evaluation	2,915,932	2,868,281		2,868,281	2,973,036		2,973,036

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Defense-Wide
FY 2017 President's Budget
Exhibit R-1 FY 2017 President's Budget
Total Obligational Authority
(Dollars in Thousands)

08 Jan 2016

Appropriation -----	FY 2015 (Base & OCO)	FY 2016 Base Enacted	FY 2016 OCO Enacted	FY 2016 Total Enacted	FY 2017 Base	FY 2017 OCO	FY 2017 Total
-----	-----	-----	-----	-----	-----	-----	-----
Defense Advanced Research Projects Agency	2,915,932	2,868,281		2,868,281	2,973,036		2,973,036
Total Research, Development, Test & Evaluation	2,915,932	2,868,281		2,868,281	2,973,036		2,973,036

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Defense-Wide
FY 2017 President's Budget
Exhibit R-1 FY 2017 President's Budget
Total Obligational Authority
(Dollars in Thousands)

08 Jan 2016

Appropriation: 0400D Research, Development, Test & Eval, DW

Line No	Program Element Number	Item	Act	FY 2015 (Base & OCO)	FY 2016 Base Enacted	FY 2016 OCO Enacted	FY 2016 Total Enacted	FY 2017 Base	FY 2017 OCO	FY 2017 Total	Se c
2	0601101E	Defense Research Sciences	01	322,030	333,119		333,119	362,297		362,297	U
4	0601117E	Basic Operational Medical Research Science	01	59,341	56,544		56,544	57,791		57,791	U
		Basic Research		381,371	389,663		389,663	420,088		420,088	
9	0602115E	Biomedical Technology	02	164,589	114,262		114,262	115,213		115,213	U
13	0602303E	Information & Communications Technology	02	315,923	341,358		341,358	353,635		353,635	U
14	0602383E	Biological Warfare Defense	02	42,447	24,265		24,265	21,250		21,250	U
17	0602702E	Tactical Technology	02	299,787	302,582		302,582	313,843		313,843	U
18	0602715E	Materials and Biological Technology	02	144,409	206,115		206,115	220,456		220,456	U
19	0602716E	Electronics Technology	02	169,690	174,798		174,798	221,911		221,911	U
		Applied Research		1,136,845	1,163,380		1,163,380	1,246,308		1,246,308	
36	0603286E	Advanced Aerospace Systems	03	123,292	173,631		173,631	182,327		182,327	U
37	0603287E	Space Programs and Technology	03	172,504	126,692		126,692	175,240		175,240	U
55	0603739E	Advanced Electronics Technologies	03	81,119	76,021		76,021	49,807		49,807	U
56	0603760E	Command, Control and Communications Systems	03	229,945	201,335		201,335	155,081		155,081	U
57	0603766E	Network-Centric Warfare Technology	03	350,323	425,861		425,861	428,894		428,894	U
58	0603767E	Sensor Technology	03	283,905	240,127		240,127	241,288		241,288	U
		Advanced Technology Development		1,241,088	1,243,667		1,243,667	1,232,637		1,232,637	
138	0605001E	Mission Support	06					69,244		69,244	U
154	0605502E	Small Business Innovative Research	06	85,266							U

R-1C1: FY 2017 President's Budget (Published Version of PB Position), as of January 8, 2016 at 09:33:10

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Defense-Wide
 FY 2017 President's Budget
 Exhibit R-1 FY 2017 President's Budget
 Total Obligational Authority
 (Dollars in Thousands)

08 Jan 2016

Appropriation: 0400D Research, Development, Test & Eval, DW

Line	Program Element			FY 2015	FY 2016	FY 2016	FY 2016	FY 2017	FY 2017	FY 2017	S
No	Number	Item	Act	(Base & OCO)	Base Enacted	OCO Enacted	Total Enacted	Base	OCO	Total	e
--	-----	----	---	-----	-----	-----	-----	-----	-----	-----	c
163	0605898E	Management HQ - R&D	06	71,362	71,571		71,571	4,759		4,759	U
		Management Support		156,628	71,571		71,571	74,003		74,003	
				-----	-----	-----	-----	-----	-----	-----	
		Total Research, Development, Test & Eval, DW		2,915,932	2,868,281		2,868,281	2,973,036		2,973,036	

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Defense Advanced Research Projects Agency
FY 2017 President's Budget
Exhibit R-1 FY 2017 President's Budget
Total Obligational Authority
(Dollars in Thousands)

08 Jan 2016

Appropriation: 0400D Research, Development, Test & Eval, DW

Program Line Element No Number	Item	Act	FY 2015 (Base & OCO)	FY 2016 Base Enacted	FY 2016 OCO Enacted	FY 2016 Total Enacted	FY 2017 Base	FY 2017 OCO	FY 2017 Total	S e c
2 0601101E	Defense Research Sciences	01	322,030	333,119		333,119	362,297		362,297	U
4 0601117E	Basic Operational Medical Research Science	01	59,341	56,544		56,544	57,791		57,791	U
Basic Research			381,371	389,663		389,663	420,088		420,088	
9 0602115E	Biomedical Technology	02	164,589	114,262		114,262	115,213		115,213	U
13 0602303E	Information & Communications Technology	02	315,923	341,358		341,358	353,635		353,635	U
14 0602383E	Biological Warfare Defense	02	42,447	24,265		24,265	21,250		21,250	U
17 0602702E	Tactical Technology	02	299,787	302,582		302,582	313,843		313,843	U
18 0602715E	Materials and Biological Technology	02	144,409	206,115		206,115	220,456		220,456	U
19 0602716E	Electronics Technology	02	169,690	174,798		174,798	221,911		221,911	U
Applied Research			1,136,845	1,163,380		1,163,380	1,246,308		1,246,308	
36 0603286E	Advanced Aerospace Systems	03	123,292	173,631		173,631	182,327		182,327	U
37 0603287E	Space Programs and Technology	03	172,504	126,692		126,692	175,240		175,240	U
55 0603739E	Advanced Electronics Technologies	03	81,119	76,021		76,021	49,807		49,807	U
56 0603760E	Command, Control and Communications Systems	03	229,945	201,335		201,335	155,081		155,081	U
57 0603766E	Network-Centric Warfare Technology	03	350,323	425,861		425,861	428,894		428,894	U
58 0603767E	Sensor Technology	03	283,905	240,127		240,127	241,288		241,288	U
Advanced Technology Development			1,241,088	1,243,667		1,243,667	1,232,637		1,232,637	
138 0605001E	Mission Support	06					69,244		69,244	U
154 0605502E	Small Business Innovative Research	06	85,266							U
163 0605898E	Management HQ - R&D	06	71,362	71,571		71,571	4,759		4,759	U

R-1C1: FY 2017 President's Budget (Published Version of PB Position), as of January 8, 2016 at 09:33:10

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Defense Advanced Research Projects Agency
 FY 2017 President's Budget
 Exhibit R-1 FY 2017 President's Budget
 Total Obligational Authority
 (Dollars in Thousands)

08 Jan 2016

Appropriation: 0400D Research, Development, Test & Eval, DW

Line	Program Element	Item	Act	FY 2015 (Base & OCO)	FY 2016 Base Enacted	FY 2016 OCO Enacted	FY 2016 Total Enacted	FY 2017 Base	FY 2017 OCO	FY 2017 Total	S e c
--	-----	-----	---	-----	-----	-----	-----	-----	-----	-----	-
	Management Support			156,628	71,571		71,571	74,003		74,003	
	Total Defense Advanced Research Projects Agency			2,915,932	2,868,281		2,868,281	2,973,036		2,973,036	

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Defense Advanced Research Projects Agency • President's Budget Submission FY 2017 • RDT&E Program

Program Element Table of Contents (by Budget Activity then Line Item Number)

Appropriation 0400: Research, Development, Test & Evaluation, Defense-Wide

Line #	Budget Activity	Program Element Number	Program Element Title	Page
2	01	0601101E	DEFENSE RESEARCH SCIENCES.....	Volume 1 - 1
4	01	0601117E	BASIC OPERATIONAL MEDICAL SCIENCE.....	Volume 1 - 49

Appropriation 0400: Research, Development, Test & Evaluation, Defense-Wide

Line #	Budget Activity	Program Element Number	Program Element Title	Page
9	02	0602115E	BIOMEDICAL TECHNOLOGY.....	Volume 1 - 55
13	02	0602303E	INFORMATION & COMMUNICATIONS TECHNOLOGY.....	Volume 1 - 67
14	02	0602383E	BIOLOGICAL WARFARE DEFENSE.....	Volume 1 - 101
17	02	0602702E	TACTICAL TECHNOLOGY.....	Volume 1 - 105
18	02	0602715E	MATERIALS AND BIOLOGICAL TECHNOLOGY.....	Volume 1 - 137
19	02	0602716E	ELECTRONICS TECHNOLOGY.....	Volume 1 - 155

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Defense Advanced Research Projects Agency • President's Budget Submission FY 2017 • RDT&E Program

Appropriation 0400: Research, Development, Test & Evaluation, Defense-Wide

Line #	Budget Activity	Program Element Number	Program Element Title	Page
36	03	0603286E	ADVANCED AEROSPACE SYSTEMS.....	Volume 1 - 181
37	03	0603287E	SPACE PROGRAMS AND TECHNOLOGY.....	Volume 1 - 201
55	03	0603739E	ADVANCED ELECTRONICS TECHNOLOGIES.....	Volume 1 - 221
56	03	0603760E	COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS.....	Volume 1 - 241
57	03	0603766E	NETWORK-CENTRIC WARFARE TECHNOLOGY.....	Volume 1 - 265
58	03	0603767E	SENSOR TECHNOLOGY.....	Volume 1 - 297

Appropriation 0400: Research, Development, Test & Evaluation, Defense-Wide

Line #	Budget Activity	Program Element Number	Program Element Title	Page
138	06	0605001E	MISSION SUPPORT.....	Volume 1 - 333
154	06	0605502E	SMALL BUSINESS INNOVATION RESEARCH.....	Volume 1 - 335
163	06	0605898E	MANAGEMENT HQ - R&D.....	Volume 1 - 337

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Defense Advanced Research Projects Agency • President's Budget Submission FY 2017 • RDT&E Program

Program Element Table of Contents (Alphabetically by Program Element Title)

Program Element Title	Program Element Number	Line #	BA	Page
ADVANCED AEROSPACE SYSTEMS	0603286E	36	03.....	Volume 1 - 181
ADVANCED ELECTRONICS TECHNOLOGIES	0603739E	55	03.....	Volume 1 - 221
BASIC OPERATIONAL MEDICAL SCIENCE	0601117E	4	01.....	Volume 1 - 49
BIOLOGICAL WARFARE DEFENSE	0602383E	14	02.....	Volume 1 - 101
BIOMEDICAL TECHNOLOGY	0602115E	9	02.....	Volume 1 - 55
COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS	0603760E	56	03.....	Volume 1 - 241
DEFENSE RESEARCH SCIENCES	0601101E	2	01.....	Volume 1 - 1
ELECTRONICS TECHNOLOGY	0602716E	19	02.....	Volume 1 - 155
INFORMATION & COMMUNICATIONS TECHNOLOGY	0602303E	13	02.....	Volume 1 - 67
MANAGEMENT HQ - R&D	0605898E	163	06.....	Volume 1 - 337
MATERIALS AND BIOLOGICAL TECHNOLOGY	0602715E	18	02.....	Volume 1 - 137
MISSION SUPPORT	0605001E	138	06.....	Volume 1 - 333
NETWORK-CENTRIC WARFARE TECHNOLOGY	0603766E	57	03.....	Volume 1 - 265
SENSOR TECHNOLOGY	0603767E	58	03.....	Volume 1 - 297
SMALL BUSINESS INNOVATION RESEARCH	0605502E	154	06.....	Volume 1 - 335
SPACE PROGRAMS AND TECHNOLOGY	0603287E	37	03.....	Volume 1 - 201
TACTICAL TECHNOLOGY	0602702E	17	02.....	Volume 1 - 105

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 1: Basic Research</i>					R-1 Program Element (Number/Name) PE 0601101E / <i>DEFENSE RESEARCH SCIENCES</i>							
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	322.030	333.119	362.297	-	362.297	361.151	365.461	372.674	376.113	-	-
BLS-01: <i>BIO/INFO/MICRO SCIENCES</i>	-	14.000	6.127	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-
CCS-02: <i>MATH AND COMPUTER SCIENCES</i>	-	111.223	144.290	149.065	-	149.065	158.762	165.583	163.036	167.036	-	-
CYS-01: <i>CYBER SCIENCES</i>	-	48.178	50.428	45.000	-	45.000	47.219	27.000	10.000	10.000	-	-
ES-01: <i>ELECTRONIC SCIENCES</i>	-	39.947	40.824	49.553	-	49.553	38.151	40.996	44.883	44.883	-	-
MS-01: <i>MATERIALS SCIENCES</i>	-	77.942	53.060	65.609	-	65.609	60.387	63.780	85.138	85.138	-	-
TRS-01: <i>TRANSFORMATIVE SCIENCES</i>	-	30.740	38.390	53.070	-	53.070	56.632	68.102	69.617	69.056	-	-

A. Mission Description and Budget Item Justification

The Defense Research Sciences Program Element is budgeted in the Basic Research Budget Activity because it provides the technical foundation for long-term National Security enhancement through the discovery of new phenomena and the exploration of the potential of such phenomena for Defense applications. It supports the scientific study and experimentation that is the basis for more advanced knowledge and understanding in information, electronic, mathematical, computer, biological and materials sciences.

The Bio/Info/Micro Sciences project will explore and develop potential technological breakthroughs that exist at the intersection of biology, information technology and micro/physical systems to exploit advances and leverage fundamental discoveries for the development of new technologies, techniques and systems of interest to the DoD. Programs in this project will draw upon information and physical sciences to discover properties of biological systems that cross multiple scales of biological architecture and function, from the molecular and genetic level through cellular, tissue, organ, and whole organism levels.

The Math and Computer Sciences project supports long term national security requirements through scientific research and experimentation in new computational models and mechanisms for reasoning and communication in complex, interconnected systems. The project is exploring novel means of leveraging computer capabilities, including: practical, logical, heuristic, and automated reasoning by machines; development of enhanced human-to-computer and computer-to-computer interaction technologies; innovative approaches to the composition of software; innovative computer architectures; mathematical programs and their potential for defense applications; and new learning mechanisms for systematically upgrading and improving these capabilities.

The Cyber Sciences project supports long term national security requirements through scientific research and experimentation in cybersecurity. Networked computing systems control virtually everything, from power plants and energy distribution, transportation systems, food and water distribution, financial systems, to defense

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 1: Basic Research</i>	R-1 Program Element (Number/Name) PE 0601101E / <i>DEFENSE RESEARCH SCIENCES</i>

systems. Protecting the infrastructure on which these systems rely is a national security issue. The Cyber Sciences project will ensure DoD cyber-capabilities survive adversary attempts to degrade, disrupt, or deny military computing, communications, and networking systems. Basic research in cyber security is required to provide a basis for continuing progress in this area. Promising research results will transition to both technology development and system-level projects.

The Electronic Sciences project explores and demonstrates electronic and optoelectronic devices, circuits and processing concepts that will provide: 1) new technical options for meeting the information gathering, transmission and processing required to maintain near-real time knowledge of the enemy and the ability to communicate decisions based on that knowledge to all forces in near-real time; and 2) provide new means for achieving substantial increases in performance and cost reduction of military systems providing these capabilities.

The Materials Sciences project provides the fundamental research that underpins the development and assembly of advanced nanoscale and bio-molecular materials, devices, and electronics for DoD applications that greatly enhance soldier awareness, capability, security, and survivability, such as materials with increased strength-to-weight ratio and ultra-low size, devices with ultra-low energy dissipation and power, novel spectroscopic sources, and electronics with persistent intelligence and improved surveillance capabilities.

The Transformative Sciences project supports research and analysis that leverages converging technological forces and transformational trends in computing and the computing-reliant subareas of the social sciences, life sciences, manufacturing, and commerce. The project integrates these diverse disciplines to improve military adaptation to sudden changes in requirements, threats, and emerging/converging trends, especially trends that have the potential to disrupt military operations.

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	332.146	333.119	328.362	-	328.362
Current President's Budget	322.030	333.119	362.297	-	362.297
Total Adjustments	-10.116	0.000	33.935	-	33.935
• Congressional General Reductions	0.000	0.000			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	0.000	0.000			
• SBIR/STTR Transfer	-10.116	0.000			
• TotalOtherAdjustments	-	-	33.935	-	33.935

Congressional Add Details (\$ in Millions, and Includes General Reductions)

Project: CCS-02: *MATH AND COMPUTER SCIENCES*

Congressional Add: *Basic Research Congressional Add*

FY 2015	FY 2016
3.334	-

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 1: Basic Research</i>		R-1 Program Element (Number/Name) PE 0601101E / <i>DEFENSE RESEARCH SCIENCES</i>	
<u>Congressional Add Details (\$ in Millions, and Includes General Reductions)</u>		FY 2015	FY 2016
Congressional Add Subtotals for Project: CCS-02		3.334	-
Project: CYS-01: <i>CYBER SCIENCES</i>			
Congressional Add: <i>Basic Research Congressional Add</i>		3.334	-
Congressional Add Subtotals for Project: CYS-01		3.334	-
Project: ES-01: <i>ELECTRONIC SCIENCES</i>			
Congressional Add: <i>Basic Research Congressional Add</i>		6.666	-
Congressional Add Subtotals for Project: ES-01		6.666	-
Project: MS-01: <i>MATERIALS SCIENCES</i>			
Congressional Add: <i>Basic Research Congressional Add</i>		6.666	-
Congressional Add Subtotals for Project: MS-01		6.666	-
Congressional Add Totals for all Projects		20.000	-
<u>Change Summary Explanation</u>			
FY 2015: Decrease reflects the SBIR/STTR transfer.			
FY 2016: N/A			
FY 2017: Increase reflects expanded focus in Math and Computer sciences, Electronics, Materials and Transformative sciences.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity					R-1 Program Element (Number/Name)				Project (Number/Name)			
0400 / 1					PE 0601101E / DEFENSE RESEARCH SCIENCES				BLS-01 / BIO/INFO/MICRO SCIENCES			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
BLS-01: BIO/INFO/MICRO SCIENCES	-	14.000	6.127	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-

A. Mission Description and Budget Item Justification

This project is investigating and developing the intersections of biology, information technology and micro/physical systems to exploit important technological advances and leverage fundamental discoveries for the development of new technologies, techniques, and systems of interest to the DoD. This research is critical to the development of improved training and cognitive rehabilitation. Programs in this project will draw upon the information and physical sciences to discover properties of biological systems that cross multiple scales of biological architecture and function, from the molecular and genetic level through cellular, tissue, organ, and whole organism levels. This project will develop the basic research tools in biology that are unique to the application of biological-based solutions to critical Defense problems.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Quantitative Models of the Brain Description: The Quantitative Models of the Brain program will establish a functional mathematical basis on which to build future advances in cognitive neuroscience, computing capability, and signal processing across the DoD. An important focus of this program will be determining how information is stored and recalled in the brain and other DoD-relevant signals, developing predictive, quantitative models of learning, memory, and measurement. Using this understanding, the program will develop powerful new symbolic computational capabilities for the DoD in a mathematical system that will provide the ability to understand complex and evolving signals and tasks while decreasing software and hardware requirements and other measurement resources. This includes a comprehensive mathematical theory to extract and leverage information in signals at multiple acquisition levels that would fundamentally generalize compressive sensing for multi-dimensional sources beyond domains typically used. New insights related to signal priors, task priors, and adaptation will enable these advances. This program will further exploit advances in the understanding and modeling of brain activity and organization to improve training of individuals and teams as well as identify new therapies for cognitive rehabilitation (e.g., Traumatic Brain Injury (TBI), Post Traumatic Stress Disorder (PTSD)). Critical to success will be the ability to detect cellular and network-level changes produced in the brain during the formation of new, hierarchically organized memories and memory classes, and to correlate those changes with memory function of animals during performance of behavioral tasks. FY 2015 Accomplishments: - Quantified spatio-temporal patterns of neurophysiological activity underlying memory formation. - Extended models and brain regions to account for hierarchical organization of memories (procedural, declarative/episodic). - Demonstrated model prediction of knowledge and skill-based memory encoding. - Developed model of memory encoding using non-invasively recorded neural signals.	9.600	6.127	-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) BLS-01 / BIO/INFO/MICRO SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Developed sparse multiple input/multiple output nonlinear dynamical modeling methodology for real-time application to electrophysiological recordings. FY 2016 Plans: - Build hippocampal-neocortical model of stimulation-based memory enhancement. - Develop and apply a new set of classification models for the prediction of behavioral outcomes from the spatio-temporal patterns of electrophysiological recordings in the hippocampus. - Develop initial computational model of integrated neural, physiological, and environmental effects in neural replay, skill acquisition, and subsequent memory recall.			
Title: Bio Interfaces Description: The Bio Interfaces program supported scientific study and experimentation, emphasizing the interfaces between biology and the physical and mathematical/computer sciences. This unique interaction developed new mathematical and experimental tools for understanding biology in a way that allowed its application to a myriad of DoD problems. These tools will help exploit advances in the complex modeling of physical and biological phenomena. It is also expected that understanding the fundamentals of biology will aid in developing tools to understand complex, non-linear networks. This program also explored the fundamental nature of time in biology and medicine. This included mapping basic clock circuitry in biological systems from the molecular level up through unique species level activities with a special emphasis on the applicability to human biology. FY 2015 Accomplishments: - Investigated alternative strategies for treating disease by targeting clocking systems that drive temporal processes such as cell cycle progression and metabolic cycles. - Leveraged temporally collected data to test the impact of time on drug efficacy. - Discovered and tested novel compounds that target oscillatory networks to modulate neurodegenerative disease in an animal model.		4.400	-
Accomplishments/Planned Programs Subtotals		14.000	6.127
C. Other Program Funding Summary (\$ in Millions)			
N/A			
Remarks			
D. Acquisition Strategy			
N/A			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) BLS-01 / BIO/INFO/MICRO SCIENCES

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity					R-1 Program Element (Number/Name)				Project (Number/Name)			
0400 / 1					PE 0601101E / DEFENSE RESEARCH SCIENCES				CCS-02 / MATH AND COMPUTER SCIENCES			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
CCS-02: MATH AND COMPUTER SCIENCES	-	111.223	144.290	149.065	-	149.065	158.762	165.583	163.036	167.036	-	-

A. Mission Description and Budget Item Justification

The Math and Computer Sciences project supports scientific study and experimentation on new computational algorithms, models, and mechanisms in support of long-term national security requirements. The project is exploring novel means of leveraging computer capabilities, including: practical, logical, heuristic, and automated reasoning by machines; enhanced human-to-computer and computer-to-computer interaction technologies; innovative approaches to the composition of software; innovative computer architectures; mathematical programs and their potential for defense applications; and new learning mechanisms for systematically upgrading and improving these capabilities. Promising techniques will transition to both technology development and system-level projects.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Big Mechanism Description: The Big Mechanism program is creating new approaches to automated computational intelligence applicable to diverse domains such as biology, cyber, economics, social science, and intelligence. Mastering these domains requires the capability to create abstract yet predictive - ideally causal - models from massive volumes of diverse data generated by human actors, physical sensors, and networked devices. Current modeling approaches are heavily reliant on human insight and expertise, but the complexity of these models is growing exponentially and has now, or will soon, exceed the capacity for human comprehension. Big Mechanism will create technologies to extract and normalize information for incorporation in flexible knowledge bases readily adapted to novel problem scenarios; powerful reasoning engines that can infer general rules from a collection of observations, apply general rules to specific instances, and generate (and compute the likelihood of) the most plausible explanations for a sequence of events; and knowledge synthesis techniques to derive abstract principles and/or create models of extreme complexity consistent with huge volumes of data. Big Mechanism applications will accommodate an operator-in-the-loop by accepting questions posed in human natural language, providing drill-down to reveal the basis for an answer, taking user inputs to improve/correct derived associations, weightings, and conclusions, and querying the operator to clarify ambiguities and reconcile detected inconsistencies. Big Mechanism techniques will integrate burgeoning data into causal models and explore these models for precise interventions. The program has adopted cancer modeling as an initial focus because the availability of experimental data, and the complexity of the problems are representative of challenges facing the DoD in areas such as cyber attribution, open-source intelligence, and economic indications and warning. FY 2015 Accomplishments: - Developed model management techniques for storing, manipulating, and reasoning about tens of thousands of alternative causal models. - Developed techniques to generate plausible causal hypotheses that can be tested in the lab.	15.000	23.100	25.000

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CCS-02 / MATH AND COMPUTER SCIENCES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Developed tools for operator drill-down, ambiguity clarification, and inconsistency reconciliation. - Demonstrated an initial capability to read thousands of published papers on various aspects of the Ras cancer pathway; extract the specifics of the results (e.g., Ras model fragments) being reported in each paper; and assemble Ras model fragments into a larger consolidated model of Ras biochemical interactions. FY 2016 Plans: - Demonstrate automated testing of machine-generated hypotheses. - Create new modes for visualizing and exploring models of huge scope that in their entirety exceed human cognitive capabilities. - Develop causal models that relate phenotype to genotype using biological big data. - Formulate statistical approaches for uncovering causal relationships in numerical data/time series and categorical data/symbol sequences. - Demonstrate prototype technologies in production mode by identifying drug targets and drugs for one or more specific classes of cancer. - Develop algorithms for early indications and/or tracking of medical conditions such as neurological impairment, musculoskeletal injury, and cardio-vascular issues. FY 2017 Plans: - Create interfaces and tools to support a public web-based resource of machine-curated cancer pathways. - Create utilities to add genomic information to machine-curated cancer pathways. - Publish a high-fidelity simulation of the Ras cancer pathway. - Explore the portability of Big Mechanism technologies to other domains. - Explore the application of genotype-phenotype models to biomanufacturing. - Develop and implement scalable algorithms that reveal causality networks in large, complex, heterogeneous datasets.				
Title: Building Resource Adaptive Software from Specifications (BRASS) Description: The Building Resource-Adaptive Software from Specifications (BRASS) program is developing an automated framework that permits software systems to seamlessly adapt to changing resource conditions in an evolving operational environment. Effective adaptation is realized through rigorously defined specifications that capture application resource assumptions and resource guarantees made by the environment. The current manual adaptation process is based on corrective patching, which is time-consuming, error-prone, and expensive. Predicting the myriad of possible environment changes that an application may encounter in its lifetime is problematic, and existing reactive approaches are brittle and often incorrect. The use of specification-based adaptation will allow BRASS applications to be correctly restructured in real time whenever stated assumptions or guarantees are broken. This restructuring is optimized to trade off execution fidelity and functionality for continued operation. BRASS will create tools to automatically discover and monitor resource changes, build new analyses to infer deep		5.996	15.500	20.919

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CCS-02 / MATH AND COMPUTER SCIENCES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
resource-based specifications, and implement compiler and runtime transformations that can efficiently adapt to resource changes. FY 2015 Accomplishments: - Developed a preliminary evaluation framework to enable assessment of adaptation strategies for software systems in the face of resource changes. - Identified promising technical approaches to automatically discover and monitor resource changes. FY 2016 Plans: - Integrate specifications within an operational environment to monitor resource changes and trigger signals when resource invariants are violated. - Develop compile-time and runtime transformations that ensure survivable operation in the face of unexpected environment changes. - Build validation tools that certify that transformed applications satisfy specification assumptions in the context of new operating environment guarantees. - Develop platform-specific challenge problems from different military domains. FY 2017 Plans: - Develop new forms of resource-sensitive specifications capable of defining complex resource changes involving both physical and logical resources. - Build new compiler and runtime infrastructure that are sensitive to ecosystem evolution. - Incorporate lightweight monitoring tools capable of runtime verification of adaptive program transformations. - Evaluate the effectiveness of the developed systems in collaboration with potential transition partners.				
Title: Quantifying Uncertainty in Physical Systems Description: The Quantifying Uncertainty in Physical Systems thrust will create the basic mathematics needed to efficiently quantify, propagate and manage multiple sources of (parametric and model) uncertainty to make accurate predictions about and also design stochastic, complex DoD systems. In particular, this will include new methods for scaling Uncertainty Quantification (UQ) methods to multiscale/multiphysics DoD systems; techniques for correcting model-form uncertainty and for understanding rare events; and new methods for decision making, control, and design under uncertain conditions. FY 2015 Accomplishments: - Initiated development of new dimensional reduction and surrogate model methods with theoretical error bounds for rigorous uncertainty analysis of large-scale, coupled systems. - Initiated development of a new theoretical framework for optimization in the presence of high dimensional uncertain parameters.		4.350	16.947	19.357

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CCS-02 / MATH AND COMPUTER SCIENCES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Initiated development of new model from uncertainty approaches that outperform traditional methods such as the Gaussian Process approach for accurate estimation of quantities of interest in physical systems. FY 2016 Plans: - Develop scalable approximation methods with provable error bounds for optimization in the presence of high dimensional uncertain parameters. - Develop scalable Bayesian inference algorithms for inverse methods with orders of magnitude speed-up incorporating the known physical properties of DoD systems. - Derive proofs and theoretical treatment of rare event detection algorithms within risk-based optimization framework. - Explore novel interfaces for computational design tools that incorporate material structures and physics to enable simultaneous design exploration and optimization under uncertainty. FY 2017 Plans: - Develop new mathematical design techniques for high-dimensional multi-physics problems in the presence of high-dimensional uncertainty. - Initiate design work on a specific DoD multi-fidelity and multi-physics challenge problem. - Implement algorithms for estimation of quantities in physical systems in the presence of uncertainty on emerging high-performance computing platforms. - Develop new multi-fidelity techniques for model error estimation. - Demonstrate the use of novel computational design interfaces that incorporate material structures and physics to enable simultaneous design exploration and optimization under uncertainty.				
Title: Young Faculty Award (YFA) Description: The goal of the Young Faculty Award (YFA) program is to encourage junior faculty at universities and their equivalent at non-profit science and technology research institutions to participate in sponsored research programs that will augment capabilities for future defense systems. This program focuses on cutting-edge technologies for greatly enhancing microsystems technologies, biological technologies and defense sciences. The long-term goal for this program is to develop the next generation of scientists, engineers, and mathematicians in key disciplines who will focus a significant portion of their careers on DoD and National Security issues. The aim is for YFA recipients to receive deep interactions with DARPA program managers, programs, performers, and the user community. Current activities include research in thirteen topic areas spanning from Quantum Science and Technology to Robotics and Supervised Autonomy, Mathematics, Computing, and the Interface of Engineering and Biology. A key aspect of the YFA program is DARPA-sponsored military visits; all YFA Principal Investigators are expected to participate in one or more military site visits to help them better understand DoD needs. FY 2015 Accomplishments:		15.166	17.279	18.000

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CCS-02 / MATH AND COMPUTER SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Awarded new FY 2015 grants for new two-year research efforts across the topic areas, establishing a new set of appropriate technologies to solve current DoD problems. - Continued FY 2014 research on new concepts for microsystem technologies, biological technologies and defense sciences, by exercising second year funding, and by providing continued mentorship by program managers. - Awarded Director's Fellowships for top FY 2013 participants based on researcher's refined technology development and transition plans. FY 2016 Plans: - Award new FY 2016 grants for new two-year research efforts across the topic areas, establishing a new set of appropriate technologies to solve current DoD problems. - Continue FY 2015 research on new concepts for microsystem technologies, biological technologies and defense sciences, by exercising second year funding, and by providing continued mentorship by program managers. - Award Director's Fellowships for top FY 2014 participants. During this additional year of funding researchers will refine their technology further and align to DoD needs. FY 2017 Plans: - Award new FY 2017 grants for new two-year research efforts across the topic areas, establishing a new set of appropriate technologies to solve current DoD problems. - Continue FY 2016 research on new concepts for microsystem technologies, biological technologies and defense sciences, by exercising second year funding, and by providing continued mentorship by program managers. - Award Director's Fellowships for top FY 2015 participants. During this additional year of funding researchers will refine their technology further and align to DoD needs.			
Title: Communicating With Computers (CWC) Description: The Communicating With Computers (CWC) program is advancing the state-of-the-art in human-computer interaction by enabling computers to comprehend language, gesture, facial expression and other communicative modalities in context. Human language is inherently ambiguous and so humans depend strongly on perception of the physical world and context to make language comprehensible. CWC aims to provide computers with analogous capabilities to sense the physical world, encode the physical world in a perceptual structure, and link language to this perceptual encoding. To accomplish this, CWC will apply and extend research in language, vision, gesture recognition and interpretation, dialog management, cognitive linguistics, and the psychology of visual encoding, which are essential for human communication in the physical world. CWC will also work to extend the communication techniques developed for physical contexts to nonphysical contexts such as virtual constructs in the cyber domain. CWC advances will impact military application areas such as robotics and command and control. FY 2015 Accomplishments:		5.250	13.576
			16.213

UNCLASSIFIED

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CCS-02 / MATH AND COMPUTER SCIENCES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Developed a hardware and a software platform for humans to communicate with machines using speech and gestures. - Formulated representations for the physical world that can capture the information in a visual scene in a form amenable to annotation and modification by language-based inputs. - Created a semantic framework for gesture, facial expression and other communicative modalities. FY 2016 Plans: - Explore methods for determining whether transmitted communications have been successfully received and, if not, what additional communications are most likely to result in success. - Implement representations for the physical world and develop connectors to large-scale knowledge bases to enable visual-language synergies. - Build a universal corpus of elementary composable ideas that in combination can convey the meaning of most communications. FY 2017 Plans: - Develop and demonstrate the capability to make computer inputs using gesture, facial expression and other communicative modalities. - Implement initial techniques for confirming that communications have been successfully received and extrapolating potentially missing information. - Demonstrate human-machine communication and collaboration on a physical problem solving task.				
Title: Mining and Understanding Software Enclaves (MUSE) Description: The Mining and Understanding Software Enclaves (MUSE) program is developing program analyses and frameworks for improving the resilience and reliability of complex software applications at scale. MUSE techniques will apply machine learning algorithms to large software corpora to repair likely defects and vulnerabilities in existing programs and to discover new programs that conform to desired behaviors and specifications. MUSE frameworks will enable robust execution of large-scale and data-intensive computations. Specific technical challenges include persistent semantic artifact generation and analysis, defect identification and repair, pattern recognition, and specification inference and synthesis. MUSE research will improve the security of intelligence-related applications and enhance computational capabilities in areas such as automated code maintenance and revision management, low-level systems implementation, graph processing, entity extraction, link analysis, high-dimensional data analysis, data/event correlation, and visualization. FY 2015 Accomplishments: - Implemented new static and dynamic program analysis techniques structured to interact with a persistent database of program facts collected from deep semantic analysis of a large software corpus. - Designed application programming interfaces and implementations of a preliminary mining engine that supports the efficient injection, querying, inspection, and optimization of the underlying database.		8.000	12.200	16.000

UNCLASSIFIED

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CCS-02 / MATH AND COMPUTER SCIENCES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Extended the corpus with richer semantic ontologies and metadata support to deal with diverse language frameworks, environments, and systems at scale. - Demonstrated an initial capability by automatically finding and repairing a Heartbleed bug through the addition of bounds checks. FY 2016 Plans: - Implement scalable database technologies and mining algorithms that allow the ingestion and analysis of tens of millions of lines of open-source software. - Integrate machine learning algorithms that can direct and assimilate mining activities on analysis artifacts stored in the database. - Evaluate component-level synthesis techniques to build implementations for complex self-contained algorithms. - Demonstrate the effectiveness of the developed systems. FY 2017 Plans: - Implement scalable database technologies and mining algorithms that allow the ingestion and analysis of hundreds of millions of lines of open-source software. - Apply deep learning algorithms on complex graph structures produced by corpus mining to discover latent relationships among corpus elements for automated program repair and synthesis. - Exploit ideas from program sketching, user-guided feedback, and specification-driven analysis to automatically construct implementations of complex protocols from discovered specifications. - Evaluate the effectiveness of the developed systems in collaboration with potential transition partners.				
Title: Knowledge Representation Description: The Knowledge Representation thrust will develop much-needed tools to contextualize and analyze heterogeneous scientific data, facilitating field-wide hypothesis generation and testing. This will be accomplished by focusing on two key efforts: the development of domain-agnostic mathematical tools for representing heterogeneous data and domain knowledge in a unified knowledge framework, and domain-specific computational tools to embed observable data within the framework and enable tangible discoveries through computational analysis. To demonstrate the applicability of Knowledge Representation technology to multiple complex systems, the thrust will include validation across multiple disparate scientific and engineering fields. The technology developed under this thrust will revolutionize the process of scientific discovery by efficiently maximizing the potential of large, heterogeneous, multi-scale datasets across numerous complex scientific fields. FY 2015 Accomplishments: - Developed an initial mathematical knowledge framework for representing diverse data types and existing domain knowledge in a domain-agnostic form.		12.000	11.600	12.000

UNCLASSIFIED

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CCS-02 / MATH AND COMPUTER SCIENCES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Established initial scientific and/or engineering use case and example data sets that will be used to validate the knowledge representation framework and tools as they are developed. - Designed appropriate tools for ingesting and registering scientific data into a common mathematical representation and demonstrated the tools for example datasets. FY 2016 Plans: - Demonstrate data input and information extraction within the previously developed mathematical knowledge framework. - Incorporate domain-specific prior knowledge, such as computational models, into the mathematical knowledge framework. - Demonstrate the integration of datasets and prior domain knowledge in one or more scientific and engineering use cases. - Explore novel mathematical representations that can accommodate the possibilities of new materials for enabling simultaneous design exploration and optimization. - Develop a quantitative framework for analyzing and optimizing human interactions with engineered components in collaborative networks consisting of human-machine systems and systems-of-systems. - Explore novel experimental approaches for repeatable and replicable testing of social simulation representation and modeling tools for understanding social behavioral outcomes. FY 2017 Plans: - Develop a prototype platform for knowledge and data ingestion. - Demonstrate multimodal integration and inference with first-generation analysis tools. - Demonstrate hypothesis generation and steering using newly developed knowledge representation tools on one or more scientific and engineering use cases. - Analyze and optimize knowledge representation system performance in terms of scalability for inference and knowledge ingestion. - Demonstrate novel mathematical representation tools that integrate geometry with material physics and properties and micro-structure to accelerate design exploration and optimization. - Demonstrate the utility of new networked data collection, mathematical, and computational modeling tools in the simulation of complex social interactions. - Demonstrate the applicability of newly developed representation and modeling tools for understanding potential social behavioral outcomes. - Design tools for the measurement and representation of collaborative problem solving performance in human-machine systems and systems-of-systems. - Demonstrate the use of new knowledge representation tools for modeling and optimizing collaborative problem solving performance in human-machine systems and systems-of-systems.				
Title: Probabilistic Programming for Advancing Machine Learning (PPAML)		13.611	13.188	9.576

UNCLASSIFIED

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CCS-02 / MATH AND COMPUTER SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
Description: The Probabilistic Programming for Advancing Machine Learning (PPAML) program is creating an advanced computer programming capability that greatly facilitates the construction of new machine learning applications in a wide range of domains. This capability will increase the number of people who can effectively contribute, make experts more productive, and enable the creation of new tactical applications that are inconceivable given today's tools. The key enabling technology is a radically new programming paradigm called probabilistic programming that enables developers to quickly build generative models of phenomena and queries of interest, which a compiler would convert into efficient applications. PPAML technologies will be designed for application to a wide range of military domains including Intelligence, Surveillance and Reconnaissance (ISR) exploitation, robotic and autonomous system navigation and control, and medical diagnostics. FY 2015 Accomplishments: - Identified and developed two additional challenge problems from natural language processing and automated image captioning with increasing levels of complexity and larger data sets. - Extended the front end of a probabilistic programming system with additional functionality, including profilers, debuggers, and model verification/checking tools. - Extended the back end of a probabilistic programming system with additional functionality, such as improving efficiency of solvers and compiling inference engines to a range of different hardware targets. - Evaluated the performance of probabilistic programming approaches in collaboration with potential transition partners. FY 2016 Plans: - Demonstrate advanced probabilistic abstractions, inference techniques, and implementations. - Enrich the front end of probabilistic programming systems with new abstractions, and improve integration with solvers and inference engines. - Extend the back end of a probabilistic programming system with support for new inference techniques. - Evaluate the performance of each probabilistic programming system both in terms of the quality of the answers and the levels of resources required. FY 2017 Plans: - Demonstrate the benefit of probabilistic programming systems over existing techniques. - Integrate probabilistic systems within domain-specific contexts to provide tailored functionality. - Build new solvers that incorporate state-of-the-art machine learning algorithms that operate at scales at least one order of magnitude greater than currently feasible. - Work with domain experts and transition partners to apply the program-developed tools to relevant domains.			
Title: Secure Programming Languages (SPL)		-	12.000

UNCLASSIFIED

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Appropriation/Budget Activity 0400 / 1		R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES		Project (Number/Name) CCS-02 / MATH AND COMPUTER SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
Description: The Secure Programming Languages (SPL) program will create new programming languages and integrated development environments that facilitate the creation of secure computer programs. At present, programming languages allow programmers to create programs having large attack surfaces, major flaws, and critical vulnerabilities. Minimizing the attack surface, correcting flaws, and eliminating vulnerabilities are the programmer's responsibility, and the degree to which the programmer succeeds depends largely on the skill of the programmer. The languages developed by SPL will break this paradigm by incorporating security features in the language itself that ensure formal correctness throughout all phases of the software development lifecycle. SPL languages and integrated development environments will facilitate the creation of software free from broad classes of flaws and vulnerabilities, and enable even novice programmers to readily create secure computer programs. FY 2017 Plans: - Formulate approaches for automatically identifying non-essential components in software programs and systems that can be eliminated to minimize the attack surface. - Develop programming languages, tools, and integrated development environments that facilitate the creation/adaptation of software free from broad classes of flaws and vulnerabilities. - Formulate approaches for automatically proving formal correctness at critical stages of the software development lifecycle.					
Title: Unconventional Processing of Signals for Intelligent Data Exploitation (UPSIDE) Description: The objective of the Unconventional Processing of Signals for Intelligent Data Exploitation (UPSIDE) program is to achieve extreme power savings while increasing performance for object detection and tracking from video streams by using an unconventional, approximate computing approach. Today, image processing applications use high precision, digital representations, which are inherently power-inefficient, particular for data produced by noisy, analog, real-time sensors such as video. UPSIDE's unconventional approach uses pattern matching techniques that map very efficiently to both analog complementary metal-oxide semiconductor (CMOS) circuits and various emerging devices. Furthermore, this pattern matching approach can leverage the physics of certain emerging devices to compute a best pattern match directly requiring very little power. The UPSIDE computing approach will be benchmarked using a DoD-relevant image processing pipeline, to verify gains in both throughput and power efficiency. The result will be new approach for image processing systems that demonstrate five orders of magnitude improvement, in terms of combined power and performance for the mixed signal implementations, and seven orders of magnitude improvements using the emerging devices. The UPSIDE program will create a new generation of computing structures that will, in turn, enable revolutionary advances in Intelligence, Surveillance and Reconnaissance (ISR) processing, particularly for DoD applications of embedded, real-time sensor data analysis. FY 2015 Accomplishments:			20.000	18.000	-

UNCLASSIFIED

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CCS-02 / MATH AND COMPUTER SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Completed an image processing pipeline system for performing object identification and tracking utilizing a newly developed probabilistic pattern match (inference) methodology, running on conventional digital processing hardware showing no loss in accuracy over standard methods. - Completed design of the mixed-signal CMOS chip(s) for doing inference computing in an image processing pipeline system and validated by an object identification and tracking simulation using real-time, high-definition video streams. - Fabricated mixed-signal CMOS chip(s) designed to perform inference computation for use in image processing. - Demonstrated the operation of (non-CMOS) emerging devices performing an inference computation, which can be scaled for use in portable, power constrained image processing applications. FY 2016 Plans: - Build and complete mixed-signal CMOS test bed for running image processing applications performing object ID and tracking. - Complete the digital version of image processing pipeline and validate power, performance and accuracy of UPSIDE inference methodology for object identification and tracking in surveillance video. - Complete final full test bed system demonstration of mixed signal CMOS chip(s) fabricated in the UPSIDE program showing significant power savings and performance increase (100,000x better combined) over digital version for object identification and tracking applications. - Complete evaluation of a simulation of the image processing pipeline system based on (non-CMOS) emerging devices, for the primary computing, projecting 1000x performance improvement while reducing power consumption of the processing by 10,000x with no loss in tracking accuracy as compared to the conventional image processing pipeline.			
Title: Graph-theoretical Research in Algorithm Performance & Hardware for Social networks (GRAPHS) Description: While the DoD has been extremely effective in deploying rigorous analytical and predictive methods for problems involving continuously valued variables (tracking, signals processing), analytical methods for discrete data such as graphs and networks have not kept pace. Recent evidence has shown that network analysis can provide critical insight when used in DoD-relevant scenarios. In this paradigm, nodes represent items of interest and their relationships or interactions are edges; the result forms a network or graph. Current analysis of large networks, however, is just in its infancy: the composition of real-world networks is understood only at the most coarse and basic details (diameter, degree distribution). In order to implement network techniques efficiently and usefully, a better understanding of the finer mathematical structure of these networks is needed. This includes the development of a comprehensive and minimal mathematical set that characterizes networks of DoD interest and a description of how these quantities vary in both space and time. FY 2015 Accomplishments: - Created a suite of systematic network analysis tools that can be applied to static and dynamic network structures and complex use cases.		4.902	2.900
			-

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CCS-02 / MATH AND COMPUTER SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Developed near real-time scalable algorithms and models with guaranteed accuracy performance for inference, decision support, and understanding macro-phenomena. FY 2016 Plans: - Extend previously developed statistical graph models to enable the modeling of multi-scale graphs, heterogeneous and vector link structures. - Deliver code for streaming and scalable algorithms (graph matching, similarity, etc.) for large scale networks to be incorporated into software toolkit. - Deliver data-driven graph clustering and analysis methods that allow scientific discovery of complex time-varying phenomena. Title: Complexity Management Hardware Description: The battlefield of the future will certainly have more data generators and sensors that produce information required to efficiently execute operations. With networked sensors, the variety and complexity of the information streams will be even further extended. This project studied silicon designs which help alleviate the complexity inherent in next generation systems. These systems will have increasingly large data sets generated by their own multidomain sensors (such as RF and Electro-Optical/Infrared (EO/IR) payloads) as well as new inputs from external sensors that may or may not have been planned for initially. With current programming approaches, there are laborious coding requirements needed to assimilate new data streams. However, the context provided by these data sets is ever changing, and it is imperative for the integrated electronics to adapt to new information without a prolonged programming cycle. Providing contextual cues for processing of data streams will alleviate the fusion challenges that are currently faced, and which stress networked battlefield systems. As opposed to the intuition and future-proofing that is required at the programming stage of a current system, the silicon circuit of the future will be able to use contextual cues to adapt accordingly to new information as it is provided. The fundamental aspects of this program looked at various algorithms to explore the ability to use context to adapt to new information. Applied research for the program was budgeted in PE 0602303E, Project IT-02. FY 2015 Accomplishments: - Developed new, biology-inspired, neural network, machine learning algorithms including new data representations, low precision and ability to adapt and scale. - Identified and selected benchmark calculations on data streams to show accurate pattern recognition with minimal training times in a variety of applications.			
Accomplishments/Planned Programs Subtotals		3.614	-
			-
		107.889	144.290
		149.065	
		FY 2015	FY 2016
Congressional Add: Basic Research Congressional Add		3.334	-

UNCLASSIFIED

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CCS-02 / MATH AND COMPUTER SCIENCES	
		FY 2015	FY 2016
FY 2015 Accomplishments: - Supports increased efforts in basic research that engage a wider set of universities and commercial research communities.			
Congressional Adds Subtotals		3.334	-
C. Other Program Funding Summary (\$ in Millions) N/A			
Remarks			
D. Acquisition Strategy N/A			
E. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 1					R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES				Project (Number/Name) CYS-01 / CYBER SCIENCES			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
CYS-01: CYBER SCIENCES	-	48.178	50.428	45.000	-	45.000	47.219	27.000	10.000	10.000	-	-

A. Mission Description and Budget Item Justification

The Cyber Sciences project supports long term national security requirements through scientific research and experimentation in cyber security. During the past decade, information technologies have enabled important new military capabilities and driven the productivity gains essential to U.S. economic competitiveness. Unfortunately, during the same period, cyber threats have grown rapidly in sophistication and number, putting sensitive data, classified computer programs, and mission-critical information systems at risk. The basic research conducted under the Cyber Sciences project will produce the breakthroughs necessary to ensure the resilience of DoD information systems to current and emerging cyber threats. Promising research results will be transitioned to both technology development and system-level projects.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Transparent Computing	10.357	17.119	18.321
Description: The Transparent Computing program is developing technologies to enable the implementation of more effective security policies across distributed systems. The scale and complexity of modern information systems obscures linkages between security-related events, the result being that detection of attacks and anomalies must rely on narrow contextual information rather than complete knowledge of the event's provenance. This shortcoming facilitates attacks such as advanced persistent threats (APTs). The Transparent Computing program will address these problems by creating the capability to propagate security-relevant information and ensure component interactions are consistent with established behavior profiles and policies. Transparent Computing technologies are particularly important for large integrated systems with diverse components such as distributed surveillance systems, autonomous systems, and enterprise information systems. FY 2015 Accomplishments: - Formulated approaches for tracking information flows and other causal dependencies, and recovering event provenance to enable more effective detection of attacks, anomalies, and advanced persistent threats. - Proposed active/continuous testing and adaptive security policy schemes that adjust security posture and usage controls in response to information provided by distributed protection components. - Introduced dynamic behavioral attestation techniques, and proposed scalable algorithms and implementations. FY 2016 Plans: - Implement adaptive security policy schemes in software prototypes and perform initial assessments in simulated laboratory and cloud environments. - Develop and implement behavioral attestation techniques in software prototypes scalable to big data applications.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CYS-01 / CYBER SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Develop and implement causal dependency tracking across software/hardware abstraction layers. FY 2017 Plans: - Develop provenance graph analytics algorithms for clustering, role discovery, anomaly detection, root cause analysis and extrapolation. - Develop a preliminary integrated provenance tracking system for Android Java applications. - Develop defensive response mechanisms and a forensic analysis capability for a single system with browser and apps. - Conduct an adversarial evaluation of an APT browser implementation based on an operational APT scenario to infer the nature of the attack, against Transparent Computing-defined metrics.			
Title: Space/Time Analysis for Cybersecurity (STAC) Description: The Space/Time Analysis for Cybersecurity (STAC) program is developing techniques to detect vulnerabilities to algorithmic complexity and side channel attacks in software. Historically, adversaries have exploited software implementation flaws through buffer and heap overflow attacks. Advances in operating systems have largely mitigated such attacks, so now cyber adversaries must find new ways of compromising software. Algorithmic complexity and side channel attacks are emerging as the next generation of attacks since they depend on intrinsic properties of the algorithms themselves rather than implementation flaws. News reports have highlighted the first wave of these attacks (CRIME, BREACH, Hash DoS). The STAC program seeks to develop new analysis tools and techniques to detect vulnerabilities to these attacks in the software upon which the U.S. government, military, and economy depend. FY 2015 Accomplishments: - Presented initial program analysis approaches for identifying vulnerabilities to algorithmic complexity and side channel attacks based on both time and space resource usage. - Developed STAC concept of operations, created example resource usage attack scenarios, and defined the rules of engagement for competitive experiments between research and adversarial challenge teams. - Identified the initial infrastructure required to support the development of a sufficient number of challenge programs containing known vulnerabilities to support realistic evaluations. FY 2016 Plans: - Define the formal semantics of the runtime environments in which vulnerable software runs and encode these semantics in a form consumable by automated analysis tools. - Produce initial analysis tools that reason about data and control flow paths in computer programs, identify inputs adversaries can use to mount algorithmic complexity attacks, and identify outputs that adversaries can use to mount side channel attacks.		12.239	15.078
			16.360

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CYS-01 / CYBER SCIENCES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Perform the first competitive experiment using prototype analysis tools to find vulnerabilities to algorithmic complexity and side channel attacks in a corpus of challenge programs, and produce measurements of research progress against program metrics. FY 2017 Plans: - Demonstrate capabilities to detect algorithmic resource usage vulnerabilities using automated program analysis based tools. - Assess the performance of tools that identify inputs adversaries can use to mount algorithmic complexity attacks and outputs that adversaries can use to mount side channel attacks. - Identify the most promising analysis tools for finding vulnerabilities to algorithmic complexity and side channel attacks in a corpus of test programs, and integrate these in a best-of-breed prototype.				
Title: SafeWare Description: The SafeWare program is developing new code obfuscation techniques for protecting software from reverse engineering. At present, adversaries can extract sensitive information from stolen software, which can include cryptographic private keys, special inputs/failsafe modes, proprietary algorithms and even the software architecture itself. Today's state of the art in software obfuscation adds junk code (loops that do nothing, renaming of variables, redundant conditions, etc.), which unfortunately does little more than inconvenience the aggressor. Recent breakthroughs in theoretical cryptography have the potential to make software obfuscation into a mathematically rigorous science, very much like what the Rivest-Shamir-Adleman (RSA) algorithm did for the encryption of messages in the 1970's. The SafeWare program aims to take this very early-stage theory, which in its present form incurs too much runtime overhead to be practical, and re-tool its mathematical foundations such that one day it will be practical and efficient. As with RSA, SafeWare methods will require the solution of a computationally hard mathematical problem as a necessary condition for a successful de-obfuscation attack. FY 2015 Accomplishments: - Formulated new cryptographic approaches for protecting software from reverse engineering with mathematically proven security properties that are not substantially diminished in effectiveness even if they are fully understood by the adversary. - Introduced cryptographic code obfuscation methods with reduced program runtime overhead. - Studied the potential for implementing cryptographic code obfuscation techniques on multiprocessor systems. FY 2016 Plans: - Explore potentially powerful new primitives for cryptographic program obfuscation such as multilinear maps. - Develop alternate notions and models of obfuscation that accommodate specialized aggressor models. - Optimize domain-specific algorithms for obfuscation efficiency. - Create an evaluation platform/environment capable of quantifying runtime efficiency and cryptographic security of the obfuscation algorithms and software implementations, and initiate assessments. FY 2017 Plans:		10.000	12.826	10.319

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) CYS-01 / CYBER SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Based on initial assessment results, develop new obfuscation theory and implementations better suited to codes encountered in operational systems. - Use adversarial techniques to identify side channel vulnerabilities in the obfuscation algorithms and software implementations. - Work with potential transition partners to incorporate specific obfuscation features and capabilities that address use cases relevant to military systems and missions.			
Title: Automated Program Analysis for Cybersecurity (APAC) Description: Automated Program Analysis for Cybersecurity (APAC) is developing automated program analysis techniques for mathematically validating specified security properties of mobile applications. This will involve creating new and improved type-based analysis, abstract interpretation, and flow-based analysis methods with far greater ability to accurately demonstrate security with lower instances of false alarms. APAC technologies will enable developers and analysts to identify mobile applications that contain hidden malicious functionality and bar those applications from DoD mobile application marketplaces. FY 2015 Accomplishments: - Significantly improved the productivity of analysts to bar malware from DoD application stores using the prototype tools. - Assessed and selected prototype tools for experimentation or transition based on their performance on program metrics: probabilities of false alarm, missed detection rate, and human analysis time. - Transitioned new program analysis techniques to major commercial industry products. FY 2016 Plans: - Run comparative performance evaluations between program-developed malware detection tools and commercially available tools. - Engage in experiments and pilot deployments of prototype tools with transition partners running DoD application stores. - Improve prototypes to enhance usability in the context of DoD application stores.		12.248	5.405
Accomplishments/Planned Programs Subtotals		44.844	50.428
		FY 2015	FY 2016
Congressional Add: Basic Research Congressional Add		3.334	-
FY 2015 Accomplishments: - Supports increased efforts in basic research that engage a wider set of universities and commercial research communities.			
Congressional Adds Subtotals		3.334	-
C. Other Program Funding Summary (\$ in Millions)			
N/A			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / <i>DEFENSE RESEARCH SCIENCES</i>	Project (Number/Name) CYS-01 / <i>CYBER SCIENCES</i>
C. Other Program Funding Summary (\$ in Millions) <u>Remarks</u> D. Acquisition Strategy N/A E. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.		

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 1					R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES				Project (Number/Name) ES-01 / ELECTRONIC SCIENCES			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
ES-01: ELECTRONIC SCIENCES	-	39.947	40.824	49.553	-	49.553	38.151	40.996	44.883	44.883	-	-

A. Mission Description and Budget Item Justification

This project seeks to continue the phenomenal progress in microelectronics innovation that has characterized the last decades by exploring and demonstrating electronic and optoelectronic devices, circuits and processing concepts that will: 1) provide new technical options for meeting the information gathering, transmission and processing required to maintain near real-time knowledge of the enemy and the ability to communicate decisions based on that knowledge to all forces in near real-time; and 2) provide new means for achieving substantial increases in performance and cost reduction of military systems providing these capabilities. Research areas include new electronic and optoelectronic device and circuit concepts, operation of devices at higher frequency and lower power, extension of diode laser operation to new wavelength ranges relevant to military missions, development of uncooled and novel infrared detector materials for night vision and other sensor applications, development of innovative optical and electronic technologies for interconnecting modules in high performance systems, research to realize field portable electronics with reduced power requirements, and system and component level improvements to provide greater affordability and reliability. Additionally, electronically controlled microinstruments offer the possibility of nanometer-scale probing, sensing and manipulation for ultra-high density information storage "on-a-chip," for nanometer-scale patterning, and for molecular level analysis and synthesis. These microinstruments may also offer new approaches to integration, testing, controlling, manipulating and manufacturing nanometer-scale structures, molecules and devices.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Semiconductor Technology Advanced Research Network (STARNet)	20.000	20.000	20.000
Description: The Semiconductor Technology Advanced Research Network (STARNet) program is a government-industry partnership, combining the expertise and resources from select defense, semiconductor, and information companies with those of DARPA, to sponsor an external set of academic research teams that are focused on specific technology needs set by experts in industry and government. Efforts under this program will remove the roadblocks to achieving performance needed for future sensing, communication, computing, and memory applications. The program involves close collaboration between these experts and the academic base, with industry providing 60% of program funding matched by 40% from DARPA. For both industrial and government participants, leveraging shared research funding for high risk, pre-competitive technology explorations focused on shared technical hurdles is very attractive.			
Research in STARNet is divided into a discovery thrust (ACCEL) and an integration thrust (NEXT) executed by virtual academic centers and focused on exploiting current and emerging technologies to provide new capabilities. ACCEL seeks to discover new material systems, devices, and novel computing/sensing architectures. NEXT involves projects on advanced analog and mixed signal circuitry, complex system design tools, and alternative computing architectures. As the projects in ACCEL mature, it is expected that they will replace the efforts in NEXT that are based on current standard technologies for integrated circuits.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) ES-01 / ELECTRONIC SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
The STARNet program creates a community where industry and government participate as co-sponsors to guide and learn from a large academic research base (including approximately 42 universities, 171 faculty researchers, 638 students, and more than 109 industry associate personnel), with DoD shaping the goals to have direct impact on important long-range DoD needs. FY 2015 Accomplishments: - Investigated the feasibility of advanced two-dimensional semiconductor materials for extremely low power devices and developed the nanofabrication methods as well as established the theory, modeling and simulation tools for 2D electronic materials. - Researched fundamental limitations of scaling multifunctional and spintronics materials. Demonstrated advanced devices and examined device characteristics. - Developed scalable silicon-based computing system architecture by exploring the benefits of heterogeneously integrating emerging nano-technologies into silicon-based designs. - Developed statistical foundations of information processing via machine learning frameworks, process-scalable foundations of analog mixed-signal systems using information-based design metrics, neuro-principled information processing architectures for Beyond-complementary metal-oxide semiconductor (CMOS) and CMOS fabrics, and accelerated the deployment of beyond-CMOS and CMOS nanoscale fabrics via nanofunctions and nanoprimitives. - Developed components, architecture, data control, and tools for sensor swarm applications such as building energy efficiency, health care delivery, manufacturing and agriculture, and warfighter situational awareness. FY 2016 Plans: - Develop novel materials and steep-turn-on transistor devices as well as design proof-of-concept circuit blocks for applications such as lower power imagers, pattern recognition, and scavenging self-powered electronics with extremely low energy-delay product. - Develop voltage-controlled magnetic materials and fabrication techniques to enable power efficient spintronics devices for logic and memory applications. - Develop the scalability of silicon-based computing system concepts into the 2020-2030 timeframe to meet the performance, power and cost demands of DoD applications. - Discover and develop bio- and neuro-inspired information processing architecture framework that approaches the efficiency of brain computation, while aligning well with emerging beyond-CMOS nanoscale fabrics. - Investigate sensor swarm applications for Defense requirements such as warfighter situational awareness and assess system characteristics and potential advantages. FY 2017 Plans:			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) ES-01 / ELECTRONIC SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Develop low-voltage steep-turn-on transistors beyond traditional CMOS devices as well as realize the digital, memory, or microwave circuits with extremely low power consumption. - Develop spintronics devices for extremely low-power for logic and non-volatile memory circuits with increased complexity. - Develop heterogeneous and domain accelerated parallel systems by leveraging novel silicon-based computing architecture and integration concepts to enable reliable and secure system designs. - Develop statistical information processing architectures for in-memory computing and in-sensor computing by CMOS and beyond CMOS prototypes. - Develop swarm-based architecture and prototypes by leveraging localization and energy harvesting capabilities with built-in privacy and security to connect everything and enable urban or theater monitoring applications.			
Title: Direct On-Chip Digital Optical Synthesis (DODOS) Description: The development of techniques for precise frequency control of radio frequencies (RF) and microwave radiation in the 1940's revolutionized modern warfare. Frequency control is the enabling technology for radar, satellite and terrestrial communications, and positioning and navigation technology, among many other core DoD capabilities. By comparison, frequency control at optical frequencies is relatively immature, comparable to the state-of-the-art of microwave control in the 1930's. The first practical demonstration of optical frequency synthesis, utilizing a self-referenced optical comb, was performed in 1999 and, since that time, the precision and accuracy of optical measurements has improved by four orders of magnitude, including the demonstration of atomic clocks utilizing optical-frequency atomic transitions that far outperform existing technology based on microwave transitions. To date, however, optical frequency control has been constrained to laboratory experiments due to the large size, relative fragility, and high cost of optical comb-based synthesizers. Recent developments in self-referenced optical frequency combs in microscale resonators enable the development of a fully-integrated chip-scale optical frequency synthesizer. Ubiquitous low-cost robust optical frequency synthesis is expected to create a similar disruptive capability in optical technology as microwave frequency synthesis did in the 1940's, enabling high-bandwidth coherent optical communications, coherent synthesized-aperture LiDAR, portable high-accuracy atomic clocks, high-resolution standoff gas/toxin detection, and intrusion detection, among other foreseen applications. The Direct On-chip Digital Optical Synthesis (DODOS) program will investigate high-performance photonic components for creating a microscale high-accuracy optical frequency synthesizer in a compact robust package, suitable for deployment in a wide variety of mission-critical DoD applications. Significant challenges in the program include reducing the power threshold and stabilizing microresonator optical combs, developing efficient devices for on-chip second harmonic generation, and characterizing the frequency stability and phase noise of a slave laser locked to the stabilized comb. Applied research for this program is funded within PE 0602716E, Project ELT-01. FY 2015 Accomplishments:		8.181	9.700
			7.000

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) ES-01 / ELECTRONIC SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Optimized wavelength dispersion and low-threshold operation of microresonator based combs. - Explored materials and novel devices for efficient on-chip second harmonic generation. FY 2016 Plans: - Demonstrate compact low-threshold self-referenced combs suitable for DODOS integration. - Demonstrate methods for stabilizing the phase coherence of a microresonator comb across a broad optical bandwidth. - Characterize the output of a slave laser locked to a stabilized microresonator comb and evaluate the performance relative to promising DoD applications for DODOS technology. FY 2017 Plans: - Develop and demonstrate efficient electronic control algorithms to accurately sweep the slave laser across 50 nanometer (nm) of comb bandwidth. - Investigate methods to further reduce threshold of self-referenced combs. - Design and implement on-chip photonic components to mitigate issues associated with excess phase noise, cross talk, back reflection and isolation to achieve integrated DODOS system performance metrics.			
Title: Near Zero Energy RF and Sensor Operations (N-ZERO) Description: The DoD has an unfilled need for a persistent, event driven sensing capability, where physical, electromagnetic and other sensors can be pre-placed and remain dormant until awoken by an external trigger or stimulus. State-of-the-art sensors use active electronics to monitor the environment for the external trigger. The power consumed by these electronic circuits limits the sensor lifetime to durations of weeks to months. The Near Zero Power RF and Sensor Operations (N-ZERO) program will extend the lifetime of remotely deployed sensors from months to years. N-ZERO will develop the underlying technologies and demonstrate the capability to continuously and passively monitor the environment and wake-up an electronic circuit upon detection of a specific signature or trigger. Thereafter, sensor lifetime will be limited only by processing and communications of confirmed events. This program will investigate the development of highly innovative sensors and sensor architectures as well as signal processing and digitization technologies with near zero power consumption. In particular, a fundamental understanding of the trade space that simultaneously minimizes power consumption, the minimum detectable signal, and the probability of false detection will be explored. This program also has related applied research efforts funded under PE 0602716E, Project ELT-01. FY 2015 Accomplishments: - Performed data collection measurements for the purpose of designing and evaluating the performance of N-ZERO devices and microsystems in DoD relevant environments. Data collections included signatures and environmental background in acoustic,		1.600	2.500
			3.800

UNCLASSIFIED

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) ES-01 / ELECTRONIC SCIENCES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
vibrational and magnetic modalities, and environmental background data in radio frequencies (RF) of the electromagnetic spectrum. FY 2016 Plans: - Design and fabricate near zero power digitization technologies for zero power RF and physical sensor wake-up circuits. - Design and fabricate passive and extremely low power analog and digital signal processing technologies for low energy processing of RF and physical sensor signatures. - Design and fabricate innovative RF and physical sensor designs that perform passive voltage amplification and spectral processing. FY 2017 Plans: - Experimentally evaluate component technologies. - Design and fabricate improved component technologies enabling the zero power detection and classification of progressively reduced signal level RF and physical sensor signatures. - Investigate transition paths for fundamental technologies into RF communications and physical sensor systems under development in the applied research portion of this project.				
Title: High power Amplifier using Vacuum electronics for Overmatch Capability (HAVOC) Description: The effectiveness of combat operations across all domains increasingly depends on our ability to control and exploit the electromagnetic (EM) spectrum, and to deny its use to our adversaries. Below 30 GHz, the proliferation and availability of inexpensive high-power commercial RF sources has made the EM spectrum crowded and contested, challenging our spectrum dominance. The numerous tactical advantages offered by operating at higher frequencies, most notably the wide bandwidths available, is driving both commercial and DoD solid-state and vacuum electronic amplifiers into the millimeter wave (mm-wave) spectrum above 30 GHz. Control of the mm-wave spectrum necessitates advanced and increasingly more sophisticated electronic components and systems. The performance of these systems strongly depends on the available amplifier power. The High power Amplifier using Vacuum electronics for Overmatch Capability (HAVOC) program will fund basic research in the area of vacuum electronics with the ultimate goal of improving the fundamental understanding of the various phenomena governing the science and technology for the next generation of vacuum electronic amplifiers operating at mm-wave frequencies above 75 GHz. Focus areas will include modeling and simulation techniques, advanced manufacturing methods, novel beam-wave interaction structures, high current density and long-life cathodes, and other relevant topics. Applied research efforts are funded in PE 0602716E, Project ELT-01. FY 2016 Plans:		-	4.000	4.000

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / <i>DEFENSE RESEARCH SCIENCES</i>	Project (Number/Name) ES-01 / <i>ELECTRONIC SCIENCES</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Begin research into high-fidelity, three-dimensional, multi-physics, numerically efficient modeling and simulation techniques that lead to first-pass design success. - Begin investigating advanced manufacturing methods such as Selective Laser Sintering (SLS) and other additive manufacturing methods for beam-wave interaction circuits and other tube components. - Investigate a more complete fundamental understanding of electron emission enabling the a priori design of high current-density, long-life cathodes. - Design novel wideband and high-power beam-wave interaction structures. FY 2017 Plans: - Verify and validate the performance of high-fidelity, three-dimensional, multi-physics, numerically efficient modeling and simulation techniques on structures representative of advanced vacuum electronic amplifiers. - Fabricate and test wideband and high-power beam-wave interaction structures, and high current-density cathodes.			
Title: Precise Robust Inertial Guidance for Munitions (PRIGM) Description: The DoD relies on GPS for ubiquitous and accurate positioning, navigation, and timing (PNT). With the increased prevalence of intentional GPS jamming, spoofing, and other GPS-denial threats, GPS access is increasingly unavailable in contested theaters and alternative sources of PNT are required. In particular, guided munitions navigation is the most immediate and among the most demanding of GPS-denial challenges, due to the necessity of operating in highly contested theaters and the stringent requirements for minimization of cost, size, weight, and power consumption (CSWaP). The Precise Robust Inertial Guidance for Munitions (PRIGM) program will develop low-CSWaP inertial sensor technology for GPS-free munitions navigation. PRIGM comprises two focus areas: 1) Development of a Navigation-Grade Inertial Measurement Unit (NGIMU) that transitions state-of-the-art micro-electro-mechanical systems (MEMS) to DoD platforms by 2020; and 2) Research and development of Advanced Inertial MEMS Sensors (AIMS) to achieve gun-hard, high-bandwidth, high dynamic range navigation requirements with the objective of complete autonomy in 2030. PRIGM will advance state-of-the-art MEMS gyros from TRL-3 devices to a TRL-6 transition platform (complete IMU) that enables Service Labs to perform TRL-7 field demonstrations. PRIGM will exploit recent advances in heterogeneous integration of photonics and complementary metal-oxide semiconductor (CMOS) and advanced MEMS technology to realize novel inertial sensors for application in extreme dynamic environments and beyond navigation-grade performance. Future warfighting scenarios will take place in a GPS-denied world. When GPS is not available inertial sensors will provide autonomous positioning and navigation information. For successful transition to the warfighter, these sensors need to be low-CSWaP, have unprecedented precision and stability, and be immune to the perturbations of external vibrations and temperature fluctuations. PRIGM will identify, investigate, and demonstrate novel inertial sensing schemes that are capable of being		-	4.624
			4.753

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) ES-01 / ELECTRONIC SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
miniaturized once proof of concept is complete. Advanced research efforts are funded in PE 0602716E, Project ELT-01 and advanced development efforts funded in PE 0603739E, Project MT-15.			
FY 2016 Plans: - Develop models to simulate novel chip-scale inertial sensors such as optical waveguide gyroscopes and optically interrogated MEMS gyroscopes and accelerometers. - Develop MEMS and photonic integration processes demonstrating new and novel approaches to inertial sensing. - Build experimental test setup to support short-loop experiments for development of novel photonic-MEMS gyroscopes and accelerometers.			
FY 2017 Plans: - Integrate component technology and demonstrate photonic-MEMS inertial sensors with beyond-navigation-grade stability and precision. - Optimize novel optical and MEMS inertial sensor designs through modeling and simulation after completing initial experimental characterization. - Test navigation-grade inertial sensor performance robustness to external perturbations such as vibration and shock.			
Title: Quantum and Materials Basics Description: Advanced materials and novel devices have often become the basis for new and asymmetric military capabilities. The adoption of Gallium arsenide (GaAs) monolithic microwave integrated circuits greatly increased the range and effectiveness of U.S. radar systems, and recently matured Gallium Nitride (GaN) technology will be deployed with even greater capabilities. However these major investments were only possible after materials were advanced to a level of maturity that a device program could be executed. The Quantum and Materials Basics (QMB) program will investigate basic materials and device physics to mature concepts to the point that functioning components could be tested. These materials promise performance that will radically change future military systems, far exceeding the state of the art but only after they can be matured. The community is pushing towards the ultimate limits set by quantum mechanics, and managing this scaling requires fundamental research. Promising avenues of research include highly linear 1D and 2D devices and materials that would increase the dynamic range of RF transceivers; coupling of electrical, acoustic, and/or optical fields to significantly reduce the size and improve performance of RF components; and addressing the most outstanding challenges to deploying timing and sensing devices based on modern atomic physics and technology.		-	-
FY 2017 Plans: - Select candidate devices and materials for QMB development and maturation. - Determine performance targets by using basic material parameters and physics to extrapolate the limits of future military capabilities.			10.000

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) ES-01 / ELECTRONIC SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Perform proof-of-concept demonstrations to prioritize the most critical development challenges. - Create simplified devices such as transistors out of the selected materials.			
Title: Microscale Plasma Devices (MPD) Description: The goal of the Microscale Plasma Devices (MPD) program was to design, develop, and characterize MPD technologies, circuits, and substrates. The MPD program focused on development of fast, small, reliable, high carrier-density, micro-plasma switches capable of operating in extreme conditions, such as high-radiation and high-temperature environments. Specific focus was given to methods that provide efficient generation of ions that can perform robust signal processing of RF through light electromagnetic energy over a range of gas pressures. Applications for such devices are far reaching, including the construction of complete high-frequency plasma-based circuits, and microsystems with superior resistance to radiation and extreme temperature environments. MPDs were developed in various circuits and substrates to demonstrate the efficacy of different approaches. MPD-based microsystems are demonstrated in DoD applications where electronic systems must survive in extreme environments. The Basic Research part of this effort focused on fundamental MPD research to advance scientific knowledge based on the study of several key MPD design parameters. These parameters included ultra-high pressure and high carrier density regimes. MPD focused on expanding the design space for plasma devices enabling revolutionary advances in micro-plasma device performance. MPD developed innovative concepts and technologies that are clearly disruptive with respect to the current state of the art in terms of switching speed (less than 100 picoseconds), carrier density (exceeding 1E18 per cubic centimeter), and capable of operation and robustness in extreme high-radiation or high-temperature (600degC) environments. Fundamental scientific knowledge derived from MPD is also expected to drive developments in commercialization of MPD technology developed and funded in PE 0602716E, Project ELT-01. FY 2015 Accomplishments: - Completed investigations examining scaling properties for plasma devices in terms of size, density, robustness and switching speed. - Finalized studies on fundamental frequency, efficiency and power limitations of generating high-power microwave through terahertz (THz) frequency signals utilizing plasma as a robust, non-linear up-conversion medium. - Completed the optimization of devices that perform from RF through light frequencies. - Transitioned fundamental research findings into improved commercial modeling simulation and design tool capabilities, enabling DoD relevant applications that require survivability in extreme radiation and temperature environments.		2.000	-
Title: Micro-coolers for Focal Plane Arrays (MC-FPA)		1.500	-

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) ES-01 / ELECTRONIC SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
Description: The Micro-coolers for Focal Plane Arrays (MC-FPA) program developed low size, weight, power, and cost (SWaP-C) cryogenic coolers for application in high-performance infrared (IR) cameras. It is well known that the sensitivity of an IR focal-plane array (FPA) is improved by cooling its detectors to cryogenic temperatures. The disadvantages of state-of-the-art cryo-coolers are their large size, high power and high cost. On the other hand, thermoelectric (TE) coolers used in low performance IR cameras are relatively small, but are inefficient, and it is difficult to achieve temperatures below 200 Kelvin (K). To reduce IR camera SWaP-C, innovations in cooler technology are needed. This program exploited the Joule-Thomson (J-T) cooling principle, in a silicon-based Micro Electro-Mechanical Systems (MEMS) technology, to develop and demonstrate wafer-scale integrated micro-cryogenic IR FPA coolers with very low SWaP-C. MEMS microfluidics, piezoelectric MEMS, and CMOS electronics were used to demonstrate an integrated cold head and compressor, all in a semiconductor chip. This program has related applied research efforts funded under PE 0602716E, Project ELT-01. FY 2015 Accomplishments: - Demonstrated single-stage J-T cooling chip with external compressor. - Completed design and began development of the extended shortwave IR FPA. - Began preliminary design of a 3-stage J-T micro-cooler.			
Accomplishments/Planned Programs Subtotals		33.281	40.824
		FY 2015	FY 2016
Congressional Add: Basic Research Congressional Add		6.666	-
FY 2015 Accomplishments: - Supports increased efforts in basic research that engage a wider set of universities and commercial research communities.			
Congressional Adds Subtotals		6.666	-
C. Other Program Funding Summary (\$ in Millions)			
N/A			
Remarks			
D. Acquisition Strategy			
N/A			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) ES-01 / ELECTRONIC SCIENCES

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 1					R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES				Project (Number/Name) MS-01 / MATERIALS SCIENCES			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
MS-01: MATERIALS SCIENCES	-	77.942	53.060	65.609	-	65.609	60.387	63.780	85.138	85.138	-	-

A. Mission Description and Budget Item Justification

This project provides the fundamental research that underpins the development and assembly of advanced nanoscale and bio-molecular materials, devices, and electronics for DoD applications that greatly enhance soldier awareness, capability, security, and survivability, such as materials with increased strength-to-weight ratio and ultra-low size, devices with ultra-low energy dissipation and power, novel spectroscopic sources, and electronics with persistent intelligence and improved surveillance capabilities.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Nanoscale/Bio-inspired and MetaMaterials	22.140	17.210	21.300
Description: The research in this thrust area exploits advances in nano/micro-scale and bio-inspired materials, including computationally based materials science, in order to develop unique microstructures, material properties, and functionalities. This area also includes efforts to develop the underlying science for the behavior of materials whose properties have been engineered at the nano/micro-scale level, including metamaterials, bio-inspired materials for sensing and actuation, and materials that are designed to mimic biological materials from molecular to macroscopic function. Specific examples of areas of interest include materials that can self-repair, adapt, and respond for soldier protection against chemical and biological threats and novel approaches to optical based or metamaterial imaging systems capable of detecting objects in cluttered environments and around or through structural obscurants leveraging multiple degrees of freedom of light and using all photon pathways.			
FY 2015 Accomplishments: - Developed a method for screening non-natural polymer libraries for designed properties such as binding to target molecules. - Developed a method for sequencing non-natural polymers at low concentrations. - Analyzed the statistics of direct vs indirect path photons from an object in a scene, as captured by traditional imaging systems. - Analyzed the statistics of direct vs indirect path photons for imaging objects in different scenes, including inside a building, in an urban canyon, and in a military tank formation.			
FY 2016 Plans: - Use non-natural polymer synthesis and screening system to create affinity reagents against DARPA-defined targets. - Develop strategy to adapt the non-natural polymer synthesis and screening system to modify affinity reagent properties. - Initiate the development of a foundational theoretical framework, based on the Plenoptic function, for exploring the limits of exploiting multiple degrees of freedom of light and extracting the maximum amount of information from complex scenes.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) MS-01 / MATERIALS SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Initiate the design of experiments to validate theoretical models for 3D scene rendering using multiple degrees of freedom of light. FY 2017 Plans: - Improve the binding affinity of non-natural polymers against DARPA-defined targets. - Generalize developed non-natural polymer library screening strategies across multiple target classes. - Continue the development of a comprehensive Plenoptic function theoretical framework for extracting information for all photon pathways in a complex scene rendering. - Theoretically determine the fundamental limits of maximum light/scene information extraction from a single viewpoint. - Conduct laboratory experiments to validate the theoretical predictions for maximum information extraction from complex scenes using the multiple degrees of freedom described by the Plenoptic function.			
Title: Fundamentals of Nanoscale and Emergent Effects and Engineered Devices Description: The Fundamentals of Nanoscale and Emergent Effects and Engineered Devices program seeks to understand and exploit a broad range of physical properties and new physics that emerge as a result of material and/or device structure and organization at nano-scale dimensions and/or at extreme temperature and pressure. There are a wide variety of material properties that currently exist only at the nanoscale including quantized current-voltage behavior, very low melting points, high specific heats, large surface to volume ratio, high efficiency catalysis, enhanced radiative heat transfer, and correlated electron effects that arise in low dimensional systems. In addition, extreme high pressure conditions can lead to new material polymorphs or phases with dramatically enhanced physical, mechanical and functional properties. The focus of this thrust is to further characterize these emergent properties and to identify new synthesis approaches to enable access to these properties in stable, bulk material systems suitable for a wide range of DoD applications. The insights gained from research performed under this thrust will enable new, more efficient, and powerful material and device architectures that will benefit many DoD applications including controllable photonic devices that operate over multiple wavelengths, ultra-high sensitivity magnetic sensors, high-throughput biochemical sensors for known and unknown (engineered) molecules, ultra-precision air and water purification systems, materials for hypersonic aircraft, and advanced armor protection. FY 2015 Accomplishments: - Continued synthesis of suites of intermediates to lead to selected extended solids. - Initiated characterization of the physical, structural, and chemical properties of intermediates synthesized. - Furthered the development of methods to stabilize extended solids at ambient temperatures and pressures. - Based on computational analysis and experimental results, initiated design retrosynthetic pathways that are synthetically achievable for multistep reaction schemes to fabricate extended solids at reduced pressures. - Identified novel approaches for enabling three dimensional (3D) assemblies of nanoscale material constructs into micron-scale structures while preserving desirable nanoscale material properties.		16.543	14.100
			20.045

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016						
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) MS-01 / MATERIALS SCIENCES						
B. Accomplishments/Planned Programs (\$ in Millions)								
- Selected candidate nanoscale material systems with superior material properties that are amenable to 3D assembly processes. - Identified promising pick and place technologies for assembling 3D micron-scale constructs into cm-scale structures. - Began to explore the ability to assemble micron-scale, 3D, and multiple material structures from nanoscale material constructs while reserving desirable nanoscale material properties. - Initiated the pick and place assembly of cm-scale materials from micron-scale constructs while preserving desirable nanoscale material properties. FY 2016 Plans: - Continue development of methods to stabilize extended solids at ambient temperatures and pressures. - Demonstrate synthesis and stability to ambient temperature and pressure of high density extended carbon-based materials (e.g., clathrates, allotropes, and oxides) at the multimilligram scale. - Explore scalable production methods for fabrication of tough ceramic materials. - Refine and implement development of retrosynthetic pathways that are synthetically achievable for multistep reaction schemes to fabricate extended solids at reduced pressures based on computational analysis and stabilization results. - Further demonstrate the ability to assemble micron-scale, 3D, and multiple material structures from nanoscale material constructs while preserving desirable nanoscale material properties. - Continue to demonstrate pick and place assembly of cm-scale materials from micron-scale constructs while preserving desirable nanoscale material properties. - Initiate development of a computational framework for predicting the emergence of non-linear effects in complex systems. - Design an open source, agent based hardware/software platform for evaluating algorithms for modeling non-linear effects in complex systems across multiple scales. FY 2017 Plans: - Demonstrate development of methods to stabilize extended solids at ambient temperatures and pressures. - Demonstrate synthesis and stability to ambient temperature and pressure of high density extended carbon-based materials (e.g., clathrates, allotropes, and oxides) at the gram scale. - Demonstrate fabrication at the >100 gram scale and validation testing of tough ceramic materials. - Demonstrate multistep reaction synthetic pathways based on retrosynthetic designs to fabricate extended solids at reduced pressures based on retrosynthetic designs and stabilization results. - Develop nanometer and micron scale mechanical manipulation tools to support assembly tasks at the nanometer to micron scales. - Build 1 cm or larger structures with controlled internal complexity from feedstock consisting of individual atoms or molecules. - Demonstrate the ability to exploit the computing capacity offered by nonlinear systems to simulate nonlinear dynamical systems.		<table> <tr> <th>FY 2015</th><th>FY 2016</th><th>FY 2017</th></tr> <tr> <td></td><td></td><td></td></tr> </table>	FY 2015	FY 2016	FY 2017			
FY 2015	FY 2016	FY 2017						

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) MS-01 / MATERIALS SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Develop analog computing substrates for efficiently simulating systems governed by complex non-linear phenomena.			
Title: Basic Photon Science Description: The Basic Photon Science thrust is examining the fundamental science of photons, and their interactions in integrated devices, from their inherent information-carrying capability (both quantum mechanically and classically), to novel modulation techniques using not only amplitude and phase, but also orbital angular momentum. The new capabilities driven by this science will impact DoD through novel approaches to communications, signal processing, spectroscopic sensing, and imaging applications. For example, fully exploiting the computational imaging paradigm and associated emerging technologies will ultimately yield ultra-low size, weight, and power persistent/multi-functional intelligence, surveillance, and reconnaissance systems that greatly enhance soldier awareness, capability, security, and survivability. One focus of this thrust is to explore approaches for optical frequency division and harmonic generation for applications such as time distribution from ultrastable optical clocks, ultra-low phase noise microwaves, frequency references, table-top sources of coherent x-rays, and isolated attosecond pulses. In addition, this thrust will pursue novel, chip-scale optical frequency comb sources and associated technologies throughout the electromagnetic spectrum for spectroscopic sensing and demonstrate their performance with proof-of-concept studies in targeted applications. These sources will enable and spawn entirely new fields in simultaneous remote sensing, identification, and quantification of multiple trace materials in spectrally cluttered backgrounds. FY 2015 Accomplishments: - Demonstrated 30 GHz microwave output from a silica disk microresonator-based optical frequency comb and high-power photodiodes for chip-based, ultra-low phase noise microwave generation. - Demonstrated on-chip frequency comb and pulse shaping components utilizing indium phosphide based photonic integrated circuit technology and evaluated with bulk scale reference combs. - Demonstrated high flux soft x-ray production in the biologically critical water window spectral region and used this source for preliminary x-ray imaging demonstrations on the nanometer scale. - Demonstrated high efficiency-per-shot laser driven neutron production and constructed increased repetition rate sample target inserter and laser amplifiers to improve overall neutron flux for radiography applications. - Demonstrated and controlled ultra-high intensity, long wavelength lasers, which can be used to generate high average power, high energy isolated attosecond (the timescale of electron dynamics in atoms and molecules) optical pulses. - Developed and controlled microresonator-based frequency comb sources in the mid-infrared spectral region. - Developed and controlled microresonator-based frequency comb sources in the visible spectral region. - Demonstrated proof-of-concept studies of coherent control concepts for frequency comb-based spectroscopic sensing. FY 2016 Plans: - Design a rack mounted package for mode-locked laser based optical frequency division microwave source. - Demonstrate RF photonic bandpass filtering with micro-resonator optical frequency combs.		19.400	21.750
			24.264

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) MS-01 / MATERIALS SCIENCES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Demonstrate a remotely operating quartz microwave oscillator slaved via optical frequency comb based free-space (wireless) time and frequency transfer. - Demonstrate femtosecond time-resolved imaging at the nanometer scale with soft x-rays generated via high harmonic generation (tabletop scale x-ray source). - Demonstrate stability and characterization capabilities of extreme ultraviolet/soft x-ray attosecond end-station by measuring and characterizing isolated attosecond (10^-18 seconds) pulses. - Demonstrate proof-of-concept broadband chip-scale comb sources in multiple spectral regions. - Demonstrate proof-of-concept dual-comb quantum cascade lasers on the same chip in mid-infrared. - Demonstrate massively parallel spectroscopy in a lab setting for the detection of multiple trace species in a cluttered environment using chip-scale frequency combs in multiple spectral regions. - Investigate the fundamental limits of photon transduction to enable a mechanistic description of the photodetector trade space including timing, resolution, efficiency and speed. FY 2017 Plans: - Develop a rack mounted package for mode-locked laser-based optical frequency division microwave source and all components for a chip-scale source. - Demonstrate chip-scale RF photonic down conversion and filtering based on optical frequency comb technology. - Show full integration of laser and end-station to realize a microjoule, isolated attosecond beamline, representing a new capability for research in ultrafast electronics. - Demonstrate tabletop bio-imaging with nanometer spatial resolution (using tabletop high harmonic x-ray source). - Improve and tailor to specific DoD environments the performance of broadband chip-scale comb sources in multiple spectral regions. - Develop simulated field test environments for massively parallel spectroscopy for the detection of multiple trace species in a cluttered environment using chip-scale frequency combs in multiple spectral regions. - Demonstrate cavity-enhanced comb-spectroscopy methods for massively parallel spectroscopy of multiple trace species in a cluttered environment. - Determine a quantitative, first-principles description of photon detector performance for specific DoD platforms.				
Title: Enabling Quantum Technologies Description: This thrust emphasized a quantum focus on technology capabilities including significantly improved single photon sources, detectors, and associated devices useful for quantum metrology, communications, and imaging applications. It also exploited novel optical nonlinearities that can be used to combine quantum systems with classical coherent pulses to enable secure quantum communications over conventional fiber at rates compatible with commercial telecommunications. In addition, this thrust examined other novel classes of materials and phenomena that have the potential to provide novel capabilities in		13.193	-	-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) MS-01 / MATERIALS SCIENCES	

B. Accomplishments/Planned Programs (\$ in Millions)	FY 2015	FY 2016	FY 2017
the quantum regime, such as GPS-independent navigation via atom interferometry and communications, and ultrafast laser technologies. FY 2015 Accomplishments: - Developed improvements towards compact optomechanical gyroscopes. - Demonstrated techniques with better than 50 nm resolution with applications towards magnetic imaging of living cells. - Began studies to sense functional changes of electronic spin labels in biomolecules (e.g., proteins, lipids) with high spatial and temporal resolution. - Validated optimized performance of slow-beam-optical-clock. - Integrated prototype macroscopic quantum communications systems into local quantum communications testbeds. - Quantified performance of prototype macroscopic quantum communications system under realistic conditions (loss, noise, decoherence) and over secure long haul communications distances. - Developed an initial mathematical framework for predicting the emergence of quantum behavior in complex systems.			
Accomplishments/Planned Programs Subtotals	71.276	53.060	65.609

	FY 2015	FY 2016
Congressional Add: Basic Research Congressional Add	6.666	-
FY 2015 Accomplishments: - Supported increased efforts in basic research that engage a wider set of universities and commercial research communities.		
Congressional Adds Subtotals	6.666	-

C. Other Program Funding Summary (\$ in Millions)
N/A

Remarks

D. Acquisition Strategy
N/A

E. Performance Metrics
Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400 / 1					R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES				Project (Number/Name) TRS-01 / TRANSFORMATIVE SCIENCES			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
TRS-01: TRANSFORMATIVE SCIENCES	-	30.740	38.390	53.070	-	53.070	56.632	68.102	69.617	69.056	-	-

A. Mission Description and Budget Item Justification

The Transformative Sciences project supports research and analysis that leverages converging technological forces and transformational trends in information-intensive subareas of the social sciences, life sciences, manufacturing, and commerce. The project integrates these diverse disciplines to improve military adaptation to sudden changes in requirements, threats, and emerging/converging trends, especially trends that have the potential to disrupt military operations.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Living Foundries Description: The goal of the Living Foundries program is to create a revolutionary, biologically-based manufacturing platform for the DoD and the Nation. With its ability to perform complex chemistries, be flexibly programmed through DNA code, scale, adapt to changing environments and self-repair, biology represents one of the most powerful manufacturing platforms known. Living Foundries seeks to develop the foundational technological infrastructure to transform biology into an engineering practice, speeding the biological design-build-test-learn cycle and expanding the complexity of systems that can be engineered. Ultimately, Living Foundries aims to provide game-changing manufacturing paradigms for the DoD, enabling adaptable, on-demand production of critical and high-value molecules. Living Foundries will develop tools to simplify, abstract, and standardize the biological production pathway optimization process. Additionally, Living Foundries will identify the fundamental design rules that govern the construction and organization of underlying genetic elements in the production pathways. Research thrusts include developing the fundamental tools, capabilities and methodologies to accelerate the biological design-build-test cycle, thereby reducing the extensive cost and time it takes to engineer new systems and expanding the complexity and accuracy of designs that can be built. The result will be rapid design, construction, implementation, and testing of complex, higher-order genetic networks with programmable functionality. Applied research for this program is budgeted in PE 0602715E, Project MBT-02. FY 2015 Accomplishments: - Examined design tool innovations to enable forward engineering of novel genetic systems. - Investigated evaluation tools to enable massively parallel testing, validation, and verification of engineered systems. - Continued development of automated and scalable, large-scale DNA assembly and editing tools and processes.	10.250	9.250	7.185

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) TRS-01 / TRANSFORMATIVE SCIENCES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Researched new methods for integrated feedback to exploit high volume data generation and inform future designs and processes. FY 2016 Plans: - Begin demonstrating forward engineering of novel genetic systems using innovative computational design tools. - Implement evaluation tools for high-throughput testing, validation, and verification of engineered systems. - Implement novel learning systems that enable iterative design of engineered systems using integrated feedback of results to inform subsequent designs. - Incorporate automated and scalable, large-scale DNA assembly, editing tools and processes into automated, integrated design-build-test-learn technologies for engineering novel biological systems. - Develop new chassis for engineering biology for improved metabolic flux for bioproduction. FY 2017 Plans: - Improve design tools through incorporation of large scale process and test data for forward engineering novel genetic systems. - Integrate evaluation tools for high-throughput testing, validation, and verification of engineered systems. - Integrate novel learning systems that enable iterative design of engineered systems using integrated feedback of results to inform subsequent designs. - Optimize integration of design-build-test-learn technologies for high-fidelity, high-throughput, low cost engineering of biological systems. - Implement new biological chassis for improved yield and production of biochemicals.				
Title: Open Manufacturing Description: The Open Manufacturing program will reduce barriers to manufacturing innovation, speed, and affordability of materials, components, and structures. This will be achieved by investing in technologies to enable affordable, rapid, adaptable, and energy-efficient manufacturing, to promote comprehensive design, simulation and performance-prediction tools, and exposure to best practices. The applied research component of this program is funded in PE 0602715E, Project MBT-01 under Materials Processing and Manufacturing. FY 2015 Accomplishments: - Developed basic architecture and statistical environment to enable rapid qualification and certification approaches through the interaction and use of probabilistic models for process, design, and materials. - Demonstrated Micro-Induction Sintering (MIS) method for additive manufacture of metal and/or ceramic materials in complex geometries. - Demonstrated an approach to verify, validate, and quantify uncertainty in the developed rapid qualification frameworks. FY 2016 Plans:		3.750	2.038	1.800

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) TRS-01 / TRANSFORMATIVE SCIENCES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Characterize material produced using micro-induction sintering process. - Develop fundamental process modeling tools for micro-induction sintering process. - Demonstrate approach to integrate the Open Manufacturing rapid qualification frameworks into a comprehensive computational tool. FY 2017 Plans: - Establish process limits for micro-induction sintering process for specific ceramic and/or refractory material. - Analyze and quantify ability to accurately predict material properties of refractory and metal matrix composites produced using micro-induction sintering through process models previously developed, integrated with the overall Open Manufacturing framework. - Assess and quantify the uncertainty in the Open Manufacturing framework model that accurately predicts part performance based on manufacturing method, environment and integrated probabilistic models.				
Title: Biological Robustness in Complex Settings (BRICS) Description: The Biological Robustness in Complex Settings (BRICS) program will leverage newly developed technologies to enable radical new approaches for engineering biology. An emerging field, engineering biology is focused on developing the tools to harness the powerful synthetic and functional capabilities of biology. These tools will facilitate design and biological production of new chemicals and materials, sensing capabilities, therapeutics, and numerous other applications. This rapidly developing technological capability opens the door to new applications that have previously been out of reach, and offers substantial potential advantages in terms of cost and novel functionality. Fundamental work in this area will focus on understanding the underlying principles for engineering robust and safe microbes and microbial communities that perform as designed over the long-term. This program has applied research efforts funded in PE 0602715E, Project MBT-02. FY 2015 Accomplishments: - Initiated investigation of methods to engineer microorganisms that are stable over long time periods under complex growth conditions. - Initiated investigation of methods to engineer communities of microorganisms with reliably controlled population dynamics. - Began to explore methods to rationally engineer functional microbial communities. FY 2016 Plans: - Demonstrate methods to engineer organisms that are functionally stable over time in changing growth conditions. - Demonstrate methods to engineer complex communities of microorganisms with reliably controlled population dynamics.		8.849	12.080	10.235

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) TRS-01 / TRANSFORMATIVE SCIENCES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Demonstrate methods to rationally engineer functional microbial communities of increasing complexity. FY 2017 Plans: - Combine consortia engineering technologies to develop communities that can be employed to solve specific DoD-relevant problems. - Demonstrate the functional stability of engineered communities in complex environments over relevant time scales. - Demonstrate potential for safe use of engineered consortia under conditions relevant to specific applications.				
Title: Understanding Biological Complexity* Description: *Formerly Applying Biological Complexity at Scale Biological systems operate over an enormous range of spatial, physical, and temporal scales and span individual cells to multi-organism systems. This project seeks to enhance the understanding of the basic processes associated with biological network interactions, communication, and control to enable novel approaches and technology development to enhance national security. Applications range from infectious disease mitigation or prevention, to predicting and leveraging biological systems for managing communities of microorganisms. Key advances expected from this research will include the identification of approaches to create stable, predictable, and dynamic control mechanisms of biological networks. Such information will allow the determination of a biosystem's state and enable the prediction of state. FY 2016 Plans: - Investigate predictive design rules and engineering approaches for integrated biosystems. - Initiate research into biological systems with reduced complexity to facilitate predictive design for biological engineering. - Research cross-scale biological system responses to varying stimuli to understand defining characteristics of dynamic states. - Investigate dynamics and thresholds for transgene stability/instability in systems of infectious disease vectors. FY 2017 Plans: - Initiate efforts to assess the utility of new experimental model systems to inform practical engineering with complex biological systems. - Begin to identify candidate metrics and measurement technology relevant to engineering with complex biological systems. - Investigate synergistic integration of disease vector detection and control strategies.		-	9.000	10.250
Title: Modeling and Forecasting of Social Dynamics (MFSD) Description: Exploiting prior work in the areas of social media and social networks in programs such as Social Media in Strategic Communication (SMISC) in this project and Graph-theoretical Research in Algorithm Performance & Hardware for Social networks (GRAPHS) in project CCS-02, the Modeling and Forecasting of Social Dynamics (MFSD) program will develop and		-	4.500	10.000

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) TRS-01 / TRANSFORMATIVE SCIENCES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
demonstrate modeling capabilities that anticipate changes in social systems. The U.S. military works with local populations in an effort to strengthen relationships and gain new allies for purposes of security cooperation, with successful engagement fundamental to meeting these objectives. Current approaches to engagement planning are more art than science and rigorous approaches for understanding the social dynamics of local populations are lacking. MFSD will address this need by developing and demonstrating analogical societal models that, while reduced in scope, preserve the key properties of full social systems while remaining amenable to simulation. MFSD will rigorously test and validate the resulting models and establish the limits to the predictive capability they provide. Social media and other computer-mediated communications provide an important opportunity both as drivers of social dynamics and as indicators of social attitudes. The techniques that MFSD creates will enable the U.S. military to engage more effectively with local populations. FY 2016 Plans: - Formulate analogues to human social systems that preserve key properties while remaining amenable to laboratory experimentation and computational simulation. FY 2017 Plans: - Build initial analogical-model-based simulations for social phenomena. - Develop techniques for testing models for social dynamics using real-world data including historical, current events, and social media and/or other online data. - Initiate development of a decision support tool for predicting the effectiveness of alternative engagement options.				
Title: Engineering Complex Systems Description: Engineering Complex Systems will pursue new approaches to engineer complex, multi-cellular systems for enhanced capabilities and function. Complex biological materials and systems have unique properties (e.g., controlled porosity and high strength-to-weight ratios) not only because of the inherent components but also because of how those components are assembled together across length scales. Engineering biology tools and techniques are now at a stage to pursue the organization and function of multi-cellular systems for a new class of improved capabilities. This program will develop underlying technological platforms to enable information driven assembly of hierarchical multi-cellular systems for the development of advanced materials. FY 2017 Plans: - Investigate methods for specifying cellular behavior in response to environmental cues and positional information. - Begin development of biological systems that have genetically encoded three-dimensional forms of specified dimensions. - Begin development of gene expression circuits that confer desirable surface properties to a multi-cellular community.		-	-	7.500
Title: Decoding Neural Activity		-	-	6.100

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / <i>DEFENSE RESEARCH SCIENCES</i>	Project (Number/Name) TRS-01 / <i>TRANSFORMATIVE SCIENCES</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
Description: Decoding Neural Activity seeks to utilize measures of physiological state and neural intention to improve the performance of semi-autonomous and supervised machine learning systems. Through the integration of new techniques from computer science, mathematics, signal processing, and statistics, this effort will investigate new methods for combining physiological and environmental data to decode neural signals and communicate information to computational platforms. Research within this effort will include the generation of novel sensors as well as improved architecture, mathematics, and procedures underlying algorithms and analysis. Successful research in this thrust will inform the development of tools to improve the performance of interfaces and communication between humans and machines. Potential applications range from learning systems and human-machine collaboration to assisted human operations and advanced manned-unmanned system teaming. FY 2017 Plans: - Begin to develop methods to integrate physiologically generated signals with automated computational systems. - Investigate architecture, mathematics, and procedures to improve analysis and interpretation of neural signals in real-time. - Explore methods to improve signal processing for direct measurements of physiological and neurophysiological state.			
Title: Vanishing Programmable Resources (VAPR) Description: The Vanishing Programmable Resources (VAPR) program will create microelectronic systems capable of physically disappearing (either in whole or in part) in a controlled, triggerable manner. The program will develop and establish an initial set of materials and components along with integration and manufacturing capabilities to undergird a fundamentally new class of electronics defined by their performance and transience. These transient electronics ideally should perform in a manner comparable to Commercial Off-The-Shelf (COTS) systems, but with limited device persistence that can be programmed, adjusted in real-time, triggered, and/or sensitive to the deployment environment. Applications include sensors for conventional indoor/outdoor environments (buildings, transportation, and materiel), environmental monitoring over large areas, and simplified diagnosis, treatment, and health monitoring in the field. VAPR will explore transience characteristics of electronic devices and materials as well as build out an initial capability to make transient electronics a deployable technology for the DoD and Nation. The technological capability developed through VAPR will be demonstrated through a final test vehicle of a transient sensor with RF link. A basis set of transient materials and electronic components with sufficient electronic and transience performance is needed to realize transient electronic systems for environmental sensing and biomedical applications. Research and development of novel materials for implementing basic transient electronic components (actives and passives), power supply strategies, substrates and encapsulants as well as development of modes and triggers for transience will form the core of fundamental research activities. Transient components and devices developed in this technical area will form the basis for advanced functional circuit blocks and test systems to be developed in PE 0602716E, Project ELT-01.		1.815	1.522
			-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / DEFENSE RESEARCH SCIENCES	Project (Number/Name) TRS-01 / TRANSFORMATIVE SCIENCES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
FY 2015 Accomplishments: - Established an initial set of electronic materials that exhibit a useful combination of transience and the necessary physical characteristics required for sufficient electronic performance. - Demonstrated glass substrates that shatter into vanishingly small pieces when triggered with an electrical current. - Demonstrated bonding of electronic circuits to transience glass substrates and transferred glass fracturing into these electronic circuits to form vanishing electronic devices. - Demonstrated transient polymer packaging with sufficient stiffness to support electronic assemblies. - Demonstrated rapid transience of high stiffness transient polymer packaging. - Began developing and refining device modeling tools that incorporate transience effects. FY 2016 Plans: - Develop polymers with desired mechanical strength and transient characteristics for VAPR sensors. - Elucidate and model the physical mechanisms governing materials/device transience. - Integrate transient components of a sensor with RF link system (acoustic sensor, silicon RF and digital circuits, and on-board power) to demonstrate triggered disappearance of an integrated system.			
Title: Social Media in Strategic Communication (SMISC) Description: The Social Media in Strategic Communication (SMISC) program developed techniques to detect, classify, measure, and track the formation, development, and spread of ideas and concepts (memes) in social media. These techniques will provide warfighters and intelligence analysts with indications and warnings of adversary efforts to propagate purposefully deceptive messaging and misinformation. Social media creates vulnerabilities that can be exploited to threaten national security and has become a key operating environment for a broad range of extremists. SMISC developed technology and a new supporting foundational science of social networks will enable warfighters to defend against malevolent use of social media and to counter extremist influence operations. FY 2015 Accomplishments: - Integrated algorithms for meme detection and tracking with algorithms for detecting deception, persuasion, and influence operations. - Developed high fidelity diffusion models for messages, narratives, and information across social media. - Refined algorithms for sentiment analysis of content on developing social multi-media platforms.		6.076	-
Accomplishments/Planned Programs Subtotals		30.740	38.390
C. Other Program Funding Summary (\$ in Millions)			
N/A			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / <i>DEFENSE RESEARCH SCIENCES</i>	Project (Number/Name) TRS-01 / <i>TRANSFORMATIVE SCIENCES</i>
C. Other Program Funding Summary (\$ in Millions)		
Remarks		
D. Acquisition Strategy N/A		
E. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.		

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity					R-1 Program Element (Number/Name)							
0400: Research, Development, Test & Evaluation, Defense-Wide / BA 1: Basic Research					PE 0601117E / BASIC OPERATIONAL MEDICAL SCIENCE							
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	59.341	56.544	57.791	-	57.791	65.685	67.882	66.456	66.456	-	-
MED-01: BASIC OPERATIONAL MEDICAL SCIENCE	-	59.341	56.544	57.791	-	57.791	65.685	67.882	66.456	66.456	-	-

A. Mission Description and Budget Item Justification

The Basic Operational Medical Science Program Element will explore and develop basic research in medical-related information and technology leading to fundamental discoveries, tools, and applications critical to solving DoD challenges. Programs in this project address the Department's identified medical gaps in warfighter care related to health monitoring and preventing the spread of infectious disease. Efforts will draw upon the information, computational modeling, and physical sciences to discover properties of biological systems that cross multiple scales of biological architecture and function, from the molecular and genetic level through cellular, tissue, organ, and whole organism levels. To enable in-theater, continuous analysis and treatment of warfighters, this project will explore multiple diagnostic and therapeutic approaches, including the use of bacterial predators as therapeutics against infections caused by antibiotic-resistant pathogens; developing techniques to enable rapid transient immunity for emerging pathogens; and identifying fundamental biological mechanisms that enable certain species to be tolerant to various environmental insults. Advances in this area may be used as a preventative measure to mitigate widespread disease.

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	60.757	56.544	62.807	-	62.807
Current President's Budget	59.341	56.544	57.791	-	57.791
Total Adjustments	-1.416	0.000	-5.016	-	-5.016
• Congressional General Reductions	0.000	0.000			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	0.000	0.000			
• SBIR/STTR Transfer	-1.416	0.000			
• TotalOtherAdjustments	-	-	-5.016	-	-5.016

Congressional Add Details (\$ in Millions, and Includes General Reductions)

Project: MED-01: BASIC OPERATIONAL MEDICAL SCIENCE

Congressional Add: Basic Research Congressional Add

Congressional Add Subtotals for Project: MED-01

FY 2015	FY 2016
10.909	-
10.909	-

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400: Research, Development, Test & Evaluation, Defense-Wide / BA 1: Basic Research		R-1 Program Element (Number/Name) PE 0601117E / BASIC OPERATIONAL MEDICAL SCIENCE	
Congressional Add Details (\$ in Millions, and Includes General Reductions)		FY 2015	FY 2016
Congressional Add Totals for all Projects		10.909	-
Change Summary Explanation FY 2015: Decrease reflects the SBIR/STTR transfer. FY 2016: N/A FY 2017: Decrease reflects completion of several Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT) program milestones.			
C. Accomplishments/Planned Programs (\$ in Millions)	FY 2015	FY 2016	FY 2017
Title: Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT)	48.432	33.400	16.566
Description: The Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT) program will develop the underlying technologies to rapidly respond to a disease or threat and improve individual readiness and total force health protection by providing capabilities which are currently available only in centralized laboratories in the U.S. to non-tertiary care and individual settings. ADEPT will develop and exploit biological tools for the in vivo creation of nucleic acid circuits that continuously and autonomously sense and respond to changes in physiologic state and for novel methods to target delivery, enhance immunogenicity, or control activity of vaccines, potentially eliminating the time to manufacture a vaccine ex vivo. ADEPT advancements to control cellular machinery include research to optimize orthogonality and modularity of genetic control elements; identify methods to increase sensitivity and specificity; and demonstrate methods to control cellular machinery in response to changes in physiological status. ADEPT will develop methodologies for measuring health-specific biomarkers from a collected biospecimen to enable diagnostics at the point-of-need or resource limited clinical facilities (point-of-care), in-garrison or deployed. Additionally, ADEPT will develop techniques that will enable the rapid establishment of transient immunity through stimulation of the production of components of the immune system to impart effective but temporary protection. This transient immunity would bridge the time gap between the delivery of a vaccine and the development of a long term protective immune response. Applied research efforts are budgeted in PE 0602115E, Project BT-01.			
FY 2015 Accomplishments: - Collected serum from ill, convalescent, or immunized humans and identified two or more antibodies that in combination may provide disease-specific protection. - Demonstrated ability to administer nucleic acid encoding multiple antibodies to protect against existing, unmet, clinical targets; emerging global infectious diseases; and known, engineered biothreats. - Demonstrated onset of protection within hours after delivery and duration of therapeutic response greater than IV administered antibodies. - Demonstrated response and duration of antibody-encoding nucleic acid constructs similar to that conferred by administration of preformed antibodies against infectious disease in a large animal model.			

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 1: Basic Research</i>		R-1 Program Element (Number/Name) PE 0601117E / <i>BASIC OPERATIONAL MEDICAL SCIENCE</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Demonstrated optimized, high sensitivity assay methods for protein and nucleic acid biomarkers, suitable for incorporation in deployable devices. - Demonstrated advanced materials properties and incorporation of developed materials into disposable assay formats. - Demonstrated advanced methods for reagent stabilization and delivery for assays developed for deployable devices. - Demonstrated sample preparation methods in conjunction with developed assays and quantified performance metrics. - Demonstrated performance of developed assays using advance no/low power microfluidic methods. - Measured performance of developed diagnostic methods and demonstrated capability to measure clinically relevant analyte levels in appropriate biospecimen matrices. - Demonstrated in mammalian cells the function of a synthetic circuit that can control the timing and level of expression of a protein when expressed from an RNA-based expression vector. - Demonstrated in mammalian cells the function of a synthetic circuit that can integrate at least two physiological signals associated with a change in health status and respond to at least two exogenously added small molecules, and respond with a targeted change in cell state. - Demonstrated the ability to generate a synthetic antibody via continuous evolution that can specifically bind to a defined target in mammalian cells. - Investigated non-traditional approaches to treating infectious diseases. FY 2016 Plans: - Establish biodistribution maps in appropriate models resulting from varied delivery methods, formulations, and devices relevant to nucleic acid constructs for antibody production. - Demonstrate protection conferred by delivery of nucleic acid constructs encoding two or more antibodies in validated infectious disease animal model. - Submit Investigational New Drug (IND) application for transient nucleic acid-based formats against infectious disease. - Demonstrate increased protective response and duration of antibody-encoding nucleic acid constructs against infectious disease in a large animal model. - Conduct IND-enabling non-clinical studies of DNA-monoclonal antibody (mAb) candidate. - Deliver high-sensitivity assay methods for protein and nucleic acid biomarkers for incorporation into deployable devices. - Deliver advanced materials for incorporation into disposable assay formats. - Deliver advanced methods for reagent stabilization and delivery for incorporation into deployable devices. - Deliver sample preparation methods for incorporation into deployable devices. - Demonstrate optimized performance of developed bacterial/viral detection methods, assays, and materials using advanced no/low power microfluidic methods. FY 2017 Plans: - Demonstrate production of gene encoded antibodies in human safety trials.				

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 1: Basic Research</i>		R-1 Program Element (Number/Name) PE 0601117E / <i>BASIC OPERATIONAL MEDICAL SCIENCE</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Demonstrate efficacy of gene encoded antibodies in a human clinical trial. - Demonstrate the ability to identify antibodies against infectious diseases from patients in less than thirty days. - Use current good manufacturing processes to synthesize formulations for animal challenge study.				
Title: Harnessing Biological Systems Description: The Harnessing Biological Systems program will explore fundamental approaches to applying the advantages of nature's building blocks and principles in the design of biological technologies and systems. Rather than creating biomimetic designs that imitate naturally evolved capabilities this program seeks to transition to a biocentric design approach, developing tools and understanding mechanisms to leverage evolutionary advances from the start. Key advances expected from this research include identifying approaches to discover and develop new classes of dynamic therapeutics for antibiotic-resistant bacteria. One example will be to identify the underlying mechanisms by which predatory bacteria prey upon and consume other antibiotic-resistant bacteria that are pathogenic to humans. This approach represents a significant departure from conventional antibacterial therapies that rely on small molecule antibiotics. Advances in this area may be applied to a range of biological technologies including the autonomous control of epidemics. FY 2016 Plans: - Initiate studies to enhance understanding of biological adaptability in response to external pressures. - Investigate predatory bacteria effectiveness against pathogens of interest. - Initiate studies of the relevant underlying mechanisms of bacterial predation. - Identify fundamental mechanisms that control the transition between unicellular and multicellular function. - Research basic science processes by which bacteria grow and spread throughout a community. - Investigate dynamics of amoeba interactions with bacterial and fungal pathogens as a potential method for improved public health. FY 2017 Plans: - Investigate predatory bacteria effectiveness against pathogens of interest in in vivo models. - Investigate mechanisms of predation and potential resistance. - Develop quantitative models to describe predator-pathogen-host interactions. - Analyze biosynthetic pathways of the gut microbiota to discover and characterize disease tolerance-mediating metabolites.		-	10.103	13.575
Title: Analysis and Adaptation of Human Resilience Description: The Analysis and Adaptation of Human Resilience program will explore new methods to maintain and optimize warfighter health in response to environmental insults such as new and emerging infectious diseases. Projects in this area will apply recent advances in comparative biology, genetic sequencing, omics technologies, and bioinformatics to develop new tools for modulating health to ensure warfighter readiness. One approach to achieve this goal is identifying the fundamental		-	13.041	18.100

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 1: Basic Research</i>		R-1 Program Element (Number/Name) PE 0601117E / <i>BASIC OPERATIONAL MEDICAL SCIENCE</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
mechanisms that enable certain species to be tolerant to various environmental insults. Genomic and physiological analyses of a wide array of resilient animal species may be combined with sophisticated algorithms to identify important patterns of survival. By analyzing patterns in the underlying variability of host responses for resilient animals, one may formulate a survival blueprint to restore and maintain warfighter homeostasis in response to infection. This approach is orthogonal to traditional infectious disease research, which primarily relies on reducing the pathogen load through drug intervention. Projects within this program may enable discovery of novel methods to optimize human health against infectious diseases caused by multi-drug resistant pathogens. FY 2016 Plans: - Develop animal testbeds to evaluate human-relevant infection across multiple resilient species. - Assess diagnostic technologies that can rapidly detect pathogen load and characterize the different stages of infection in multiple animal species. - Analyze experimental results and bioinformatics datasets to discover key markers of tolerance. - Develop a bioinformatics library of acquired clinical retrospective data. FY 2017 Plans: - Explore methods for effectively screening animal susceptibility and disease tolerance to infection. - Collect, curate, and integrate retrospective datasets into the analysis of tolerance mechanisms. - Validate algorithms and analytical tools to facilitate the discovery of tolerance mechanisms. - Identify approaches for intervention based on novel tolerance mechanisms in animals.				
Title: Outpacing Infectious Disease Description: The Outpacing Infectious Disease thrust will investigate fundamental methods for using biology as a technology to create adaptive therapeutic response mechanisms to outpace viruses and bacteria. Today, protective measures such as antibiotics and vaccines are often circumvented by fast-mutating viruses and bacteria that evolve to create new methods for pathogenicity. New approaches, such as enabling co-evolution and co-transmission of newly developed therapeutics to ultimately outcompete the pathogen, are needed to utilize the power of evolution in vaccine and antibiotic design. Key advances expected from this research include identifying methods to discover and develop new classes of dynamic therapeutics for fast-mutating viruses and antibiotic-resistant bacteria, as well as recurrent chronic diseases. This approach represents a significant departure from conventional antibacterial and antiviral therapies, which typically rely on static solutions and continuous re-formulation and re-development in attempt to keep pace with emerging strains and disease variants. Advances in this area may be applied to the mitigation of known, new, or emerging disease. FY 2017 Plans: - Investigate approaches to design and build pathogen-derived therapeutics that control disease by interfering with the pathogen via dynamic mechanisms.		-	-	9.550

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: Research, Development, Test & Evaluation, Defense-Wide / BA 1: Basic Research		R-1 Program Element (Number/Name) PE 0601117E / BASIC OPERATIONAL MEDICAL SCIENCE		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Assess the safety, efficacy, and transmissibility of novel co-evolving therapeutics using in vitro models. - Initiate design of computational models to assess host-disease-therapeutic dynamics at the individual and population levels.				
Accomplishments/Planned Programs Subtotals		48.432	56.544	57.791
		FY 2015	FY 2016	
Congressional Add: Basic Research Congressional Add		10.909	-	
FY 2015 Accomplishments: Supports increased efforts in basic research that engage a wider set of universities and commercial research communities.				
Congressional Adds Subtotals		10.909	-	
D. Other Program Funding Summary (\$ in Millions)				
N/A				
Remarks				
E. Acquisition Strategy				
N/A				
F. Performance Metrics				
Specific programmatic performance metrics are listed above in the program accomplishments and plans section.				

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400: Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research					R-1 Program Element (Number/Name) PE 0602115E / BIOMEDICAL TECHNOLOGY							
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	164.589	114.262	115.213	-	115.213	109.817	120.852	116.651	116.651	-	-
BT-01: BIOMEDICAL TECHNOLOGY	-	164.589	114.262	115.213	-	115.213	109.817	120.852	116.651	116.651	-	-

A. Mission Description and Budget Item Justification

This Program Element focuses on applied research for medical related technology, information, processes, materials, systems, and devices. Successful battlefield medical technologies and neural interface technologies developed within this Program Element address a broad range of DoD challenges. Example battlefield medical technologies include continued understanding of infection biomarkers to lead to the development of detection devices that can be self-administered and provide a faster ability to diagnose and prevent widespread infection in-theater. Complementary battlefield technologies will be implemented in a predictive platform for forecasting disease outbreak and the capability to manufacture field-relevant pharmaceuticals in theater. New neural interface technologies will reliably extract information from the nervous system to enable control of the best robotic prosthetic-limb technology. Advanced evidence-based techniques will be developed to supplement warfighter healthcare and the diagnosis of post-traumatic stress disorder (PTSD) and mild traumatic brain injury (mTBI). FY 2015 Biomedical Technology program funding includes 117.0 million of base funding and 47.5 million congressionally added funding including \$45.0 million of Ebola emergency funding.

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	159.790	114.262	109.069	-	109.069
Current President's Budget	164.589	114.262	115.213	-	115.213
Total Adjustments	4.799	0.000	6.144	-	6.144
• Congressional General Reductions	0.000	0.000			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	8.295	0.000			
• SBIR/STTR Transfer	-3.496	0.000			
• TotalOtherAdjustments	-	-	6.144	-	6.144

Congressional Add Details (\$ in Millions, and Includes General Reductions)

Project: BT-01: BIOMEDICAL TECHNOLOGY

Congressional Add: Ebola Response and Preparedness Congressional Add (Emergency Funds)

Congressional Add: Biomedical Congressional Add

FY 2015	FY 2016
45.000	-
2.548	-

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research		R-1 Program Element (Number/Name) PE 0602115E / BIOMEDICAL TECHNOLOGY		
Congressional Add Details (\$ in Millions, and Includes General Reductions)		FY 2015	FY 2016	
Congressional Add Subtotals for Project: BT-01		47.548	-	
Congressional Add Totals for all Projects		47.548	-	
Change Summary Explanation				
FY 2015: Increase reflects reprogrammings offset by the SBIR/STTR transfer.				
FY 2016: N/A				
FY 2017: Increase reflects new focus areas in monitoring health and disease and human performance optimization.				
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Title: Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT)		27.000	22.700	13.44
Description: The overarching goal of the Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT) program is to increase our ability to rapidly respond to a disease or threat and improve individual readiness and total force health protection by providing centralized laboratory capabilities at non-tertiary care settings. ADEPT will focus on the development of Ribonucleic Acid (RNA)-based vaccines, potentially eliminating the time and labor required for traditional manufacture of a vaccine while at the same time improving efficacy. Additionally, ADEPT will develop methods to transiently deliver nucleic acids for vaccines and therapeutics, and kinetically control the timing and levels of gene expression so that these drugs will be safe and effective for use in healthy subjects. ADEPT will also focus on advanced development of key elements for simple-to-operate diagnostic devices. A companion basic research effort is budgeted in PE 0601117E, Project MED-01.				
FY 2015 Accomplishments:				
- Demonstrated the ability to control the time duration of therapeutic response to viral, bacterial, and/or antibiotic-resistant bacterial pathogens suitable for clinical use and rapid public health responses.				
- Investigated targeted delivery of nucleic acid constructs to specific cell types.				
- Demonstrated feasibility for controlling pharmacokinetics and immunity modulation components to enable a more potent and broader immune response to viral, bacterial, and/or antibiotic resistant bacterial pathogens.				
- Developed designs for RNA-based vaccines to enable transition to human clinical trials.				
- Developed designs for initial diagnostic device prototypes based on highest performing components.				
- Produced first-generation, integrated diagnostic prototypes designed for relevance to physician office, remote clinic, and low-resourced settings.				
- Measured quantitative performance of first-generation, integrated diagnostic device prototypes and determine modifications required for performance improvements.				
FY 2016 Plans:				

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602115E / <i>BIOMEDICAL TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Optimize formulation of transient nucleic acid formats for storage stability at room temperature for at least six months. - Demonstrate continuous production of nucleic acid formats for transient immunity to viral, bacterial, and/or antibiotic-resistant bacterial pathogens for population-scale use. - Incorporate device optimizations identified as a result of first-generation, integrated diagnostic device testing. - Produce integrated diagnostic device prototypes designed for relevance to physician office, remote clinic, and low-resourced settings. - Measure quantitative performance of integrated diagnostic device prototypes. FY 2017 Plans: - Initiate regulatory approval submission package for transient nucleic-acid based formats against infectious disease with safety and efficacy data. - Demonstrate production of gene encoded antibodies in human safety trials. - Conduct a dose escalation study of nucleic acid-encoded antibody against antibiotic resistant bacteria.				
Title: Restoration of Brain Function Following Trauma Description: The Restoration of Brain Function Following Trauma program will exploit recent advances in the understanding and modeling of brain activity and organization to develop approaches to treat traumatic brain injury (TBI). Critical to success will be the ability to detect and quantify functional and/or structural changes that occur in the human brain during the formation of distinct new memories, and to correlate those changes with subsequent recall of those memories during performance of behavioral tasks. This program will also develop neural interface hardware for monitoring and modulating neural activity responsible for successful memory formation in a human clinical population. The ultimate goal is identification of efficacious therapeutics approaches that can bypass and/or recover the neural functions underlying memory, which are often disrupted as a consequence of TBI. FY 2015 Accomplishments: - Identified commonalities of neural codes underlying memory formation. - Identified distinctions between neural codes underlying different classes of memories. - Identified expert memory codes for the formation of memory associations between pairs of elements (e.g., objects, locations, actions). - Initiated development of a portable computational device with integrated computational model of human memory formation. - Demonstrated task-specific improvement/restoration of memory performance in a memory task via hippocampal stimulation. FY 2016 Plans: - Refine computational model of memory toward distinguishing underlying neural activity related to forgotten memories in three categories and spatial and non-spatial associations. - Identify optimal stimulation parameters for improving performance on spatial memory tasks.		9.700	15.800	19.400

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602115E / <i>BIOMEDICAL TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Utilize defined biomarkers of memory encoding and retrieval to adaptively modulate patterned electrical stimulation to dynamically drive neural networks into states optimized for memory encoding and retrieval processes. - Determine the long-term signatures underlying stimulation-induced memory restoration tasks. - Design, develop and validate both external and implantable hardware and software systems for an integrated memory restoration system. FY 2017 Plans: - Demonstrate improvement of human performance on spatial and semantic memory tasks through the use of real-time, closed-loop, biomarker-driven stimulation. - Utilize clinical data and computational model developments to refine hardware and software components. - Fabricate and test integrated device for memory restoration in clinical patients. - Develop computational model of integrated neural, physiological, and environmental effects on neural replay and subsequent memory recall in the context of task performance relevant to military training and/or operations. - Develop and use a real-time intervention and an interface system to assess, enable, and improve skill performance in human participants.				
Title: Neuro-Adaptive Technology Description: The Neuro-Adaptive Technology program will explore and develop advanced technologies for real-time detection and monitoring of neural activity. One shortcoming of today's brain functional mapping technologies is the inability to obtain real-time correlation data that links neural function to human activity and behavior. Understanding the structure-function relationship as well as the underlying mechanisms that link brain and behavior is a critical step in providing real-time, closed-loop therapies for military personnel suffering from a variety of brain disorders. Efforts under this program will specifically examine the networks of neurons involved in post-traumatic stress disorder (PTSD), traumatic brain injury (TBI), depression, and anxiety as well as determine how to best ameliorate these disorders. The objective for this program is to develop new hardware and modeling tools to better discriminate the relationship between human behavioral expression and neural function and to provide relief through novel devices. These tools will allow for an improved understanding of how the brain regulates behavior and will enable new, disorder-specific, dynamic neuro-therapies for treating neuropsychiatric and neurological disorders in military personnel. Technologies of interest under this thrust include devices for real-time detection of brain activity during operational tasks, time synchronized acquisition of brain activity and behavior, and statistical models that correlate neural activity with human behavioral expression. FY 2015 Accomplishments: - Developed tests that activate key brain subnetworks for each functional domain. - Developed computer algorithms/programs to automatically merge elements of multimodal brain activity across time/space.		21.500	30.589	26.388

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide I BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602115E / <i>BIOMEDICAL TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Created statistical computational models of brain activity and corresponding behavior to support the neurophysiology of new therapeutic systems. - Trained decoders on a subset of domains and cross-validated on novel scan, record, and stimulate data. - Developed hardware interface stability, biocompatibility, and motion correction for recording neural activity. - Demonstrated three-dimensional, single-cell-resolution acquisition of real-time brain activity in large volumes of neural tissue. - Submitted initial, novel devices for regulatory approval. FY 2016 Plans: - Develop and apply data co-registration and fusion methods for neural activity, wiring, and behavior. - Generate and annotate first intact neural tissue volumes to elucidate microstructure and connections in three dimensions. - Design algorithms for automatic cell identification and optical-signal estimation. - Elucidate neural circuit dynamics using structurally-informed network models. - Refine optical techniques for imaging large volumes of neural tissue. - Expand data curation architecture, databases, and analytical tools to distribute generated data to the neuroscience community. - Develop methods for automatically detecting and removing noise or contamination from datasets. - Deliver a hierarchical computational model of key brain networks that captures features relevant for psychiatric illness and its treatment. - Develop and refine neural state acquisition, classification, and control algorithms to support closed-loop control in an implantable neural device. - Characterize neural network plasticity during behavioral training. FY 2017 Plans: - Complete high-resolution large-brain imaging using novel optical tools. - Demonstrate optimized optical protocols for human tissue. - Integrate neural state classification, stimulation parameters, and targeted brain networks into a comprehensive computational model to support disorder-specific closed-loop implantable neural devices. - Demonstrate real-time application of integrated disorder-specific stimulation parameters and targeted brain networks. - Utilize clinical data and computational model determinants to refine hardware and software components of an implantable neural device. - Begin fabrication of updated devices for multi-site brain stimulation. - Initiate submission process for regulatory approval of updated parameters of the novel neural device.				
Title: Prosthetic Hand Proprioception & Touch Interfaces (HAPTIX)		10.550	18.300	18.500
Description: Wounded warriors with amputated limbs get limited benefit from recent advances in prosthetic-limb technology because the user interface for controlling the limb is low-performance and unreliable. Through investments in the DARPA				

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602115E / <i>BIOMEDICAL TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Reliable Neural-Interface Technology (RE-NET) program, novel interface systems have been developed that overcome these issues and are designed to last for the lifetime of the patient. The goal of the Prosthetic Hand Proprioception & Touch Interfaces (HAPTIX) program is to create the first bi-directional (motor & sensory) peripheral nerve implant for controlling and sensing advanced prosthetic limb systems. With a strong focus on transition, the HAPTIX program will create and transition clinically relevant technology in support of wounded warriors suffering from single or multiple limb loss. FY 2015 Accomplishments: - Developed and demonstrated advanced algorithms to control prosthetic limbs using signals extracted from commercially available or newly developed electrodes. - Developed and demonstrated micro-stimulation interface technologies that provide reliable signals into the peripheral and/or central nervous system for closed-loop prosthetic control. - Performed safety and efficacy testing of novel implantable interface technology which capture motor control signals and provide electrical sensory stimulation through the peripheral nervous system. - Demonstrated bench-top functionality of next-generation peripheral interface technology. - Developed draft version of outcome metrics for quantifying effects of implantable and external system components on motor function, sensory function, pain, psychological health, and quality of life. - Developed unified virtual prosthesis environment to simulate limb motion and forces of interaction during object manipulation. FY 2016 Plans: - Integrate interface and electronic systems technology for use in human amputees to control and receive intuitive sensory feedback from a prosthetic device. - Demonstrate closed-loop control of a virtual prosthesis. - Perform safety and efficacy testing of HAPTIX system components to capture motor control signals and provide electrical sensory stimulation through the peripheral nervous system. - Demonstrate in vivo functionality of next-generation HAPTIX peripheral interface technology. - Finalize HAPTIX system prosthetic limb technology, complete sensorization, and begin manufacturing of devices. - Implement draft version of outcome metrics for quantifying effects of HAPTIX technology and begin validation studies. FY 2017 Plans: - Initiate functional validation of input/output signal transfer and wireless communication of power and data. - Conduct safety studies of HAPTIX system to support submission of investigational device exemption (IDE) application to the U.S. Food and Drug Administration (FDA). - Demonstrate novel nerve stimulation and recording technologies.				
Title: Tactical Biomedical Technologies		12.654	7.150	6.909

UNCLASSIFIED

Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602115E / <i>BIOMEDICAL TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Description: The Tactical Biomedical Technologies thrust will develop new approaches to deliver life-saving medical care on the battlefield. Uncontrolled blood loss is the leading cause of preventable death for soldiers on the battlefield. While immediate control of hemorrhage is the most effective strategy for treating combat casualties and saving lives, currently no method, other than surgical intervention, can effectively treat intracavity bleeding. A focus in this thrust was the co-development of a materials-based agent(s) and delivery mechanism capable of hemostasis and wound control for non-compressible hemorrhage in the abdominal space, regardless of wound geometry or location within that space. This thrust also investigated non-invasive techniques and equipment to use laser energy to treat intracranial hemorrhage through the skull and tissues in a pre-surgical environment. Finally, in order to address logistical delays associated with delivering necessary therapeutics to the battlefield, this thrust will also develop a pharmacy on demand that will provide a rapid response capability to enable far-forward medical providers the ability to manufacture and produce small molecule drugs and biologics. FY 2015 Accomplishments: - Developed novel continuous flow crystallizer, miniaturized reactors, and chemically compatible pumps for integration into a bench scale end-to-end manufacturing platform for the following Active Pharmaceutical Ingredients (APIs): Diphenhydramine, Diazepam, Lidocaine, Fluoxetine, Ibuprofen, Atropine, Doxycycline, Salbutamol, Ciprofloxacin, Azithromycin, Rufinamide, Etomidate, Nicardipine, and Neostigmine. - Demonstrated continuous flow synthesis, crystallization, and formulation for Salbutamol, Ciprofloxacin, Azithromycin, Rufinamide, Etomidate, Nicardipine, and Neostigmine in an integrated manufacturing platform. - Engaged the Food and Drug Administration (FDA) for input on Process Analytical Technologies (PAT) and Current Good Manufacturing Process (cGMP) for Salbutamol, Ciprofloxacin, Azithromycin, Rufinamide, Etomidate, Nicardipine, and Neostigmine. - Developed novel cell-free protein synthesis techniques using miniaturized bioreactors and/or microfluidics technologies. - Demonstrated end-to-end manufacturing of two protein therapeutics in a miniaturized platform, including the integration of protein expression and purification processes. - Engaged the FDA for input on PAT and cGMP for protein therapeutics. - Tested prototype device during in vivo pre-clinical studies for treatment of intracranial hemorrhage using laser energy through skull and tissues, and engage with the FDA on design and execution of these studies to meet FDA requirements. FY 2016 Plans: - Develop continuous synthesis of Ciprofloxacin (from basic starting materials) and Lisinopril in miniaturized integrated manufacturing platform. - Demonstrate end-to-end manufacturing and solid formulation of Ciprofloxacin in miniaturized integrated manufacturing platform. - Design and develop cell-based and cell-free protein expression of four additional biologics out of Insulin, Factor VIIa, Interferon, Hepatitis B Surface Antigen, Tissue Plasminogen Activator, Granulocyte Colony-Stimulating Factor, and Rituxmab.				

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602115E / <i>BIOMEDICAL TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Optimize miniaturized biologics manufacturing platform components, including bioreactor, purification, and analytical modules, and begin systems integration of components for both cell-based and cell-free protein expression platforms. FY 2017 Plans: - Develop continuous synthesis of Linezolid in miniaturized integrated manufacturing platform. - Demonstrate end-to-end manufacturing and solid formulation of Lisinopril and Linezolid in miniaturized integrated manufacturing platform. - Demonstrate end-to-end manufacturing of four additional biologics in miniaturized and integrated platform.				
Title: Performance Optimization in Complex Environments Description: The Performance Optimization in Complex Environments program focuses on leveraging advances in and integration of sensors, computation, and analytics to enable optimum human performance in complex environments. Device technology has advanced to the point where human beings can be instrumented with and connected to a broad range of unobtrusive, always-on physiological, cognitive, and contextual sensors and information systems. At the same time, body-area networks, wearable displays, haptics, and other novel forms of human-computer interfaces have advanced enough that convenient real-time multifactor analysis for neurofeedback and biofeedback are within reach. The Performance Optimization in Complex Environments program will first focus on developing prototyping and manufacturing techniques necessary to integrate these two advancing areas to enable optimal performance in a wide variety of activities from learning and training to specialized tasking, and to mitigate the effects of physical injury, age, and mental impairment. Research will also focus on understanding various forms of sensing and actuation to improve outcomes and how biofeedback over time can alter human capability. Technologies developed through this program will provide a foundation of novel value propositions to the warfighter in terms of restoration of lost capability, situational awareness, resilience, cognitive and physical effectiveness, and force multiplication.		-	9.650	16.475
FY 2016 Plans: - Initiate research on biological interfaces for enabling input-output of information. - Explore and identify scalable technologies for reading and writing biological signals. FY 2017 Plans: - Refine component technologies to increase scale of information input-output. - Identify component technologies to be integrated into a device for reading and writing biological signals. - Investigate novel approaches to reduce the size, weight, and power requirements for the integrated device.				
Title: Enhanced Monitoring of Health and Disease Description: The overarching goal of the Enhanced Monitoring of Health and Disease program is to leverage advanced data collection methods and capabilities to predict changes in health and spread of infectious disease from the individual to the		-	-	14.100

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602115E / <i>BIOMEDICAL TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions) population scale. While new technology platforms have enhanced our ability to respond to illness and disease, there is a need for predictive and pre-emptive technologies that enable us to correctly prepare a response prior to its obvious need. Research in this thrust will investigate new methods for the collection and detection of multiplexed biological markers as well as the analysis, correlation, and ultimate integration of vast personalized data into the clinical care information technology infrastructure. Additionally, this thrust will develop new approaches to integrate multi-source data streams to create effective predictive models of disease outbreak and spread. Technologies developed in this program will enable clinically actionable information, even when an individual has no awareness of symptoms, and extend infectious disease forecasting into a real-time, accurate capability for decision support. FY 2017 Plans: - Assess novel methods for multiplexed in vivo monitoring and wireless transmission of data related to disease biomarkers. - Collect biological samples to assess asymptomatic, symptomatic, and co-infection rates among a research cohort. - Identify key parameters of robust epidemiological models for predicting disease transmission. - Evaluate the predictive capability of dynamic, ensemble-based epidemiological models for disease forecasting.		FY 2015	FY 2016	FY 2017
Title: Dialysis-Like Therapeutics (DLT) Description: Sepsis, a bacterial infection of the blood stream, is a significant cause of injury and death among combat-injured soldiers. The goal of this program is to develop a portable device capable of controlling relevant components in the blood volume on clinically relevant time scales. Reaching this goal is expected to require significant advances in sensing in complex biologic fluids, complex fluid manipulation, separation of components from these fluids, and mathematical descriptions capable of providing predictive control over the closed loop process. The envisioned device would save the lives of thousands of military patients each year by effectively treating sepsis and associated complications. Additionally, the device may be effective as a medical countermeasure against various chemical and biological (chem-bio) threat agents, such as viruses, bacteria, fungi, and toxins. Applied research under this program further develops and applies existing component technologies and then integrates these to create a complete blood purification system for use in the treatment of sepsis. Included in this effort will be development, integration and demonstration of non-fouling, continuous sensors for complex biological fluids; implementation of high-flow microfluidic structures that do not require the use of anticoagulation; application of intrinsic separation technologies that do not require pathogen specific molecular labels or binding chemistries; and refinement of predictive modeling and control (mathematical formalism) with sufficient fidelity to enable agile adaptive closed-loop therapy. FY 2015 Accomplishments:		19.492	5.073	-

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602115E / <i>BIOMEDICAL TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Manufactured a breadboard device that integrates label-free separation technologies, high-flow fluidic architectures, and non-thrombogenic coatings for testing. - Evaluated the efficacy of the label-free separation technologies in a small-animal model. - Refined the breadboard device design based on animal testing results to inform development of a standalone benchtop integrated prototype device. - Established a clinically relevant model of sepsis in a large animal model in order to validate efficacy of separation technologies at removing pathogens and other sepsis mediators. - Performed biocompatibility studies of each component filter in the device to ensure safety in the integrated system. FY 2016 Plans: - Complete fabrication of the first generation of integrated DLT device prototypes. - Complete safety studies of the integrated DLT device in a large-animal model. - Initiate safety studies focused on pathogen removal in large-animal model.				
Title: Warrior Web Description: Musculoskeletal injury and fatigue to the warfighter caused by dynamic events on the battlefield not only impact immediate mission readiness, but also can have a deleterious effect on the warfighter throughout his/her life. The Warrior Web program will mitigate that impact by developing an adaptive, quasi-active, joint support sub-system that can be integrated into current soldier systems. Because this sub-system will be compliant and transparent to the user, it will reduce the injuries sustained by warfighters while allowing them to maintain performance. Success in this program will require the integration of component technologies in areas such as regenerative kinetic energy harvesting to offset power/energy demands; human performance, system, and component modeling; novel materials and dynamic stiffness; actuation; controls and human interface; and power distribution/energy storage. The final system is planned to weigh no more than 9kg and require no more than 100W of external power. Allowing the warfighter to perform missions with reduced risk of injuries will have immediate effects on mission readiness, soldier survivability, mission performance, and the long-term health of our veterans. FY 2015 Accomplishments: - Conducted preliminary review of Warrior Web designs and refined approaches as necessary. - Finalized open source biomechanical models to be leveraged for the Warrior Web system evaluation. - Matured design of Warrior Web system and continued parallel technology development. - Conducted preliminary evaluation of prototype Warrior Web systems via Soldier tests in laboratory environment. FY 2016 Plans: - Revise full suit design and implementation based on laboratory evaluations. - Continue to evaluate prototype Warrior Web systems via Soldier tests in laboratory and field environments.		7.245	5.000	-

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602115E / <i>BIOMEDICAL TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Continue to pursue research and development of technologies to augment human performance and support rehabilitation.				
Title: Pathogen Defeat		8.900	-	-
Description: Pathogens are well known for the high rate of mutation that enables them to escape drug therapies and primary or secondary immune responses. The Pathogen Defeat thrust area provided capabilities to predict emerging threats and the evolution of resistance of pathogens to medical countermeasures. Pathogen Defeat focused not only on known pathogens but also newly emerging pathogens and future evolution of mutations in these pathogens, allowing pre-emptive preparation of vaccine and therapy countermeasures.				
FY 2015 Accomplishments:				
- Tested predictive capabilities of trajectories to clinical viral isolates in evolution platform. - Elucidated mechanisms to explain viral escape to different pressures. - Rapidly evolved virus strains in avian cells to select vaccine candidates with antigenic similarities. - Performed objective assessment of hand-held devices for detecting biothreats and clinically-relevant pathogens.				
Accomplishments/Planned Programs Subtotals		117.041	114.262	115.213
		FY 2015	FY 2016	
Congressional Add: Ebola Response and Preparedness Congressional Add (Emergency Funds)		45.000	-	
FY 2015 Accomplishments: This program focused on the development of Ebola antibodies, vaccines, and diagnostics to enable a more rapid response to this outbreak and increase preparedness for response to future epidemics. This research utilized earlier investments by DARPA that explored technologies to discover, optimize, and deliver antibodies as a means to provide fast-acting protection against infectious diseases. A key component of this program was not only identifying effective antibodies to treat and prevent disease, but also defining and developing the antibody gene blueprint for transfer and production of vaccines. The Ebola Response and Preparedness Congressional Add is non-OCO emergency funding.				
- Conducted dose escalation study for encoded Ebola vaccine in human safety trial. - Demonstrated rapid discovery of potent antibodies from human Ebola survivors. - Evaluated protective efficacy of encoded Ebola antibodies in small and large animal models. - Tested protective efficacy of encoded Ebola vaccine in small and large animal models. - Validated cell-free production of nucleic acid-encoded antibody and vaccine formulations.				
Congressional Add: Biomedical Congressional Add		2.548	-	

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>	R-1 Program Element (Number/Name) PE 0602115E / <i>BIOMEDICAL TECHNOLOGY</i>

	FY 2015	FY 2016
FY 2015 Accomplishments: This effort furthered the development of restorative products and technologies as alternatives to amputation.		
Congressional Adds Subtotals	47.548	-

D. Other Program Funding Summary (\$ in Millions)

N/A

Remarks

E. Acquisition Strategy

N/A

F. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>					R-1 Program Element (Number/Name) PE 0602303E / <i>INFORMATION & COMMUNICATIONS TECHNOLOGY</i>							
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	315.923	341.358	353.635	-	353.635	353.925	359.959	344.530	354.091	-	-
IT-02: <i>HIGH PRODUCTIVITY, HIGH-PERFORMANCE RESPONSIVE ARCHITECTURES</i>	-	32.437	38.494	42.459	-	42.459	55.179	60.075	44.413	58.413	-	-
IT-03: <i>INFORMATION ASSURANCE AND SURVIVABILITY</i>	-	170.959	202.252	255.137	-	255.137	257.172	258.028	258.362	258.923	-	-
IT-04: <i>LANGUAGE UNDERSTANDING AND SYMBIOTIC AUTOMATION</i>	-	48.636	60.948	56.039	-	56.039	41.574	41.856	41.755	36.755	-	-
IT-05: <i>CYBER TECHNOLOGY</i>	-	63.891	39.664	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-

A. Mission Description and Budget Item Justification

The Information and Communications Technology program element is budgeted in the applied research budget activity because it is directed toward the application of advanced, innovative computing systems and communications technologies.

The High Productivity, High-Performance Responsive Architectures project is developing the necessary computing hardware and the associated software technology base required to support future critical national security needs for computationally-intensive and data-intensive applications. These technologies will lead to new multi-generation product lines of commercially viable, sustainable computing systems for a broad spectrum of scientific and engineering applications; it will include supercomputer and embedded computing systems.

The Information Assurance and Survivability project is developing the core computing and networking technologies required to protect DoD's information, information infrastructure, and mission-critical information systems. The technologies will provide cost-effective security and survivability solutions that enable DoD information systems to operate correctly and continuously even under attack.

The Language Understanding and Symbiotic Automation project develops technologies to enable computing systems to understand human speech and extract information contained in diverse media; to learn, reason and apply knowledge gained through experience; and to respond intelligently to new and unforeseen events. Enabling computing systems in this manner is of critical importance because sensor, information, and communication systems generate data at rates beyond which humans can assimilate, understand, and act. Incorporating these technologies in military systems will enable warfighters to make better decisions in complex, time-critical, battlefield environments; intelligence analysts to make sense of massive, incomplete, and contradictory information; and unmanned systems to operate safely with high degrees of autonomy.

UNCLASSIFIED

Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide I BA 2: Applied Research</i>	R-1 Program Element (Number/Name) PE 0602303E / <i>INFORMATION & COMMUNICATIONS TECHNOLOGY</i>

The Cyber Technology project develops technology to increase the security of military information systems and the effectiveness of cyber operations. Over the past decade the DoD has embraced net-centric warfare by integrating people, platforms, weapons, sensors, and decision aids. Adversaries seek to limit this force multiplier through cyber attacks intended to degrade, disrupt, or deny military computing, communications, and networking systems. Technologies developed under the Cyber Technology project will ensure DoD net-centric capabilities survive adversary cyber attacks and will enable new cyber-warfighting capabilities.

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	324.407	356.358	364.076	-	364.076
Current President's Budget	315.923	341.358	353.635	-	353.635
Total Adjustments	-8.484	-15.000	-10.441	-	-10.441
• Congressional General Reductions	0.000	0.000			
• Congressional Directed Reductions	0.000	-15.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	1.831	0.000			
• SBIR/STTR Transfer	-10.315	0.000			
• TotalOtherAdjustments	-	-	-10.441	-	-10.441

Change Summary Explanation

FY 2015: Decrease reflects reprogrammings offset by the SBIR/STTR transfer.

FY 2016: Decrease reflects congressional reduction.

FY 2017: Decrease reflects completion of the Power Efficiency Revolution For Embedded Computing Technologies (PERFECT) and Robust Automatic Translation of Speech (RATS) programs.

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY				Project (Number/Name) IT-02 / HIGH PRODUCTIVITY, HIGH-PERFORMANCE RESPONSIVE ARCHITECTURES			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
IT-02: HIGH PRODUCTIVITY, HIGH-PERFORMANCE RESPONSIVE ARCHITECTURES	-	32.437	38.494	42.459	-	42.459	55.179	60.075	44.413	58.413	-	-

A. Mission Description and Budget Item Justification

The High Productivity, High-Performance Responsive Architectures project is developing high-productivity, high-performance computer hardware and the associated software technology base required to support future critical national security needs for computationally-intensive and data-intensive applications. These technologies will lead to new multi-generation product lines of commercially viable, sustainable computing systems for a broad spectrum of scientific and engineering applications; it will include both supercomputer and embedded computing systems. The goal will be to create not just larger computing platforms, but to extract information out of large and chaotic data sets efficiently. One of the major challenges currently facing the DoD is the prohibitively high cost, time, and expertise required to build complex computing systems including software and hardware. Powerful new approaches and tools are needed to enable the rapid and efficient production of new software, including software that can be easily changed to address new requirements and can adjust dynamically to platform and environmental perturbations. The project will ensure accessibility and usability to a wide range of application developers, not just computational science experts.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Complexity Management Hardware	7.500	11.194	10.000
Description: The battlefield of the future will have more data generators and sensors to provide information required for successful combat operations. With networked sensors, the variety and complexity of the information streams will be even further extended. The Complexity Management Hardware program will develop silicon designs which help alleviate the complexity inherent in next generation systems. These systems will have increasingly large data sets generated by their own multidomain sensors (such as RF and Electro-Optical/Infrared (EO/IR) payloads) as well as potentially new inputs from external sensors. With current programming approaches, there are laborious coding requirements needed to accommodate new data streams. Additionally, the context provided by these data sets is ever changing, and it is imperative for the integrated electronics to adapt to new information without a prolonged programming cycle. Providing contextual cues for processing data streams will alleviate the fusion challenges that are currently faced, and which stress networked battlefield systems. As opposed to the intuition and future-proofing that is required at the programming stage of a current system, the silicon circuit of the future will be able to use contextual cues to adapt accordingly to new information as it is provided. The applied research aspects of this program will investigate circuit design which can exploit the algorithms showing benefit for complexity management. This will entail various sparse versus dense data manipulations with hardware implementations catered			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY	Project (Number/Name) IT-02 / HIGH PRODUCTIVITY, HIGH-PERFORMANCE RESPONSIVE ARCHITECTURES	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
to both types of data. The program will show hardware implementations that gracefully handle multiple data streams and limit the programming burden for a complex scenario. Basic research efforts are funded in PE 0601101E, Project CCS-02.			
FY 2015 Accomplishments: - Designed complexity management processor algorithm and benchmark tests for object recognition in still images and action recognition in video. - Demonstrated critical features of algorithm including ability to learn and adapt while operating. - Quantified impact of using low precision, sparse network connectivity on accuracy of results.			
FY 2016 Plans: - Design transistor level circuits implementing the complexity management algorithms. - Demonstrate the ability to manage multiple data streams with interlaced information. - Create initial hardware verification of concepts for both sparse and hardware demonstrations.			
FY 2017 Plans: - Compare various algorithms ability to manage complex data sets. - Quantify the benefits of various architecture approaches to management of large data streams when overlaid with contextual information. - Translate the initial algorithms to high level circuit implementations to show the power and processing requirements.			
Title: Power Efficiency Revolution For Embedded Computing Technologies (PERFECT)		24.937	17.800
Description: The Power Efficiency Revolution For Embedded Computing Technologies (PERFECT) program will provide the technologies and techniques to overcome the power efficiency barriers which currently constrain embedded computing systems capabilities and limit the potential of future embedded systems. The warfighting problem this program will solve is the inability to process future real time data streams within real-world embedded system power constraints. This is a challenge for embedded applications, from Intelligence, Surveillance and Reconnaissance (ISR) systems on unmanned air vehicles through combat and control systems on submarines. The PERFECT program will overcome processing power efficiency limitations by developing approaches including near threshold voltage operation, massive and heterogeneous processing concurrency, new architecture concepts, and hardware and software approaches to address system resiliency, combined with software approaches to effectively utilize resulting system concurrency and optimized data placement to provide the required embedded system processing power efficiency. The remaining efforts under the PERFECT program will emphasize the implementation of near threshold and specialization approaches to address processing efficiency.			-
FY 2015 Accomplishments:			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / <i>INFORMATION & COMMUNICATIONS TECHNOLOGY</i>	Project (Number/Name) IT-02 / <i>HIGH PRODUCTIVITY, HIGH-PERFORMANCE RESPONSIVE ARCHITECTURES</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
systems that are optimized for regular, predictable access. The movement of data between memory and processors now requires more time and energy than the logical operations themselves. This is the result of generations of systems that architecturally separate computing/data manipulation and main data storage. Large systems have shown utilization (percentage of system peak throughput capability used) drop from as high as 90% to in the order of 2% due to the data patterns for different applications. To resolve this problem, the PALS program will develop technologies, architectures, and software approaches that move critical data processing kernels and critical data organization operations adjacent to the memory itself, rather than at physically distant general computing nodes, addressing data latency, overall computational performance and power for critical data intensive elements of an application. The PALS approach is not to physically or functionally move processing entirely to the memory, but rather to move specific, critical data intensive components of an application to the data. The result will dramatically improve performance for data intensive applications, by off-loading the main processor of data-intensive operations, and enabling data security operations at the memory itself. This will be accomplished by utilizing industry advances in 3D packaging, particularly the bandwidth, latency and power advances being developed in 3D memory stacks; new software approaches for data management; investigating alternative data movement technologies such as co-designing processor and photonic hardware, exploiting the high bandwidth provided by silicon photonics. It will also include incorporation of domain specific logic for unique and asymmetric data-intensive DoD functional capabilities at all appropriate levels of a processing system's memory. The performance and efficiency will be transformational for data analytics for both big data and embedded data-intensive DoD applications and enable real-time analysis on dynamic graphs in the fields of cyber security, threat detection, and numerous others. FY 2016 Plans: - Identify common graph primitives that would accelerate the execution of DoD-specific applications. - Explore the applications benefitting from the unique architecture and whether unique hardware design allows for processors for unique military applications. - Identify domain specific primitives that would accelerate performance by moving data-intensive functionality to appropriate processing system data storage levels and specifically a memory 3D stack logic layer. FY 2017 Plans: - Develop domain specific concepts for functionality at the hierarchical levels of data storage levels, define logic and data orchestration capabilities at these layers of storage and processing, define customization versus programmability trade-offs, and define logic layer processing concepts. - Simulate performance of PALS for selected high value application specific and data-intensive applications. - Develop initial architectural trade-offs and implementation options.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY		Project (Number/Name) IT-02 / HIGH PRODUCTIVITY, HIGH-PERFORMANCE RESPONSIVE ARCHITECTURES	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
- Develop PALS based security concepts for data management in multi-security level environments.					
Title: Electronic Globalization Description: Approximately 66% of all installed semiconductor wafer capacity is in Asia. This creates a significant risk for the DoD as off-shore manufacturing of microelectronic components could introduce various vulnerabilities to DoD systems that utilize these non-U.S. fabricated electronic components. As the DoD is faced with this globalization reality, it is essential to prevent potential consequences such as reverse engineering, and the theft of U.S. intellectual property. New applied research technology enablement will be developed in the Electronics Globalization program to provide a means of assessing the impact of high stress upon Government Off-The-Shelf (GOTS) and Commercial Off-The-Shelf (COTS) components produced in conventional contemporary foundries. The potential application of these components in extreme stresses DoD systems and makes it even more important to understand the new physics mechanisms to be expected in these regimes. The extendibility of existing reliability models, and the calibration of new reliability models for components operated outside of typical use conditions will be studied. Further, the insight gained from understanding these impacts will inform the use of elevated stress burn-in and screening tools, potentially allowing shorter and more effective test times in the fabrication plant. FY 2016 Plans: - Improve the signal-to-noise ratio of the Navy system, allowing its use in a wider array of microelectronic parts. - Study high stress effects on conventionally fabricated COTS and GOTS electronic components. - Develop device physics models which accurately capture the reliability physics behavior of semiconductors operated at elevated voltage and temperature. FY 2017 Plans: - Continue prototype system enhancements to the laser scanning tools. - Continue to study high stress effects on conventionally-fabricated COTS and GOTS electronic components. - Characterize the physics models using the response of the fabricated devices to extreme stress associated with certain DoD applications as well as accelerated life stress testing and evaluation. - Complete the development of shorter, more effective reliability screens and burn-in testing using higher stress test conditions.			-	4.000	4.000
Title: tactical CONtext EXtraction (CONEX) Description: Enriching a primary data stream with contextual information (i.e., the circumstances or facts such as who, what, and where that surround a particular event) can be accomplished by fusing data from multiple sensors. For this task, modern systems rely heavily on man-made reference signals, such as Global Positioning Systems (GPS), and preprogrammed algorithms with limited adaptability. Object recognition using Deep Learning and related approaches has been demonstrated, but these methods			-	-	6.000

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY	Project (Number/Name) IT-02 / HIGH PRODUCTIVITY, HIGH-PERFORMANCE RESPONSIVE ARCHITECTURES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
require significant offline training. The tactical CONtext EXtraction (CONEX) program will develop compact sensors and adaptive processors for extracting contextual information from resource-constrained environments. CONEX sensors will collect information from the landscape and natural sources, such as the relative position of stars, to supplement inertial measurement systems and other sensor feeds in GPS-denied areas. CONEX processors will contain embedded real-time learning algorithms that operate over multiple timescales. These adaptive methods efficiently capture complex spatial and temporal structure in noisy, ambiguous data streams that are beyond the analysis capabilities of state-of-the-art signal/image processing systems.				
FY 2017 Plans: - Refine designs of integrated circuits that implement real-time learning algorithms. - Design compact, low-power CONEX sensors to support context accumulation in selected environments. - Demonstrate performance enhancement of novel content extraction algorithms and software. - Demonstrate basic functionality of prototype CONEX sensors.				
Title: Removing Barriers to Hardware (REBHAR) Description: Small software companies are a dynamic force in the U.S. economy because they face very low barriers to innovation. Anyone can code applications for established mobile or cloud platforms and leverage the tremendous infrastructure built by larger companies to quickly access potential customers. However, commercial hardware innovations for advanced integrated circuits and Micro-Electro-Mechanical Systems (MEMS) sensors face costly obstacles that impede progress outside of large corporations. Smaller businesses generally do not have the budget or sales volume to access the latest design software, verification tools and fabrication processes. The smaller DoD market for hardware amplifies these problems for delivering revolutionary military components. The Removing Barriers to Hardware (REBHAR) program will develop methods to facilitate hardware innovation for defense applications. The objective of the REBHAR program is to establish relationships with commercial companies to gain access to proven processes, to explore the possibilities of open source hardware, and to develop an aftermarket customization strategy to economically adapt commercial chips to specific military needs.		-	-	6.000
FY 2017 Plans: - Explore the concept of open source design kits and open source hardware development cycles. - Demonstrate methods for aftermarket customization of commercial integrated circuits for select defense applications. - Demonstrate circuits based on open source design kits.				
Title: Spectrum Grand Challenge Description: The objective of the Spectrum Grand Challenge is for participants to develop wireless communications networks which can learn to cohabitate and share the same Radio Frequency (RF) spectrum as other networks without preplanning or co-		-	2.000	10.459

UNCLASSIFIED

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY	Project (Number/Name) IT-02 / HIGH PRODUCTIVITY, HIGH-PERFORMANCE RESPONSIVE ARCHITECTURES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
design of the technologies. Access to spectrum is critical to many modern sectors: military, commercial, infrastructure, public-safety, disaster recovery, and many more. Spectrum however is treated as a scarce resource typically assigned to exclusive-use licenses. These approaches still rely on exclusive use of the spectrum by only a single network. In order to meet growing spectrum demands networks must be able to dynamically adapt their use of the spectrum as needs and as spectrum conditions change, autonomously determining when, where, and how spectrum should be used. Spectrum Grand Challenge solutions will survey their environment, learn to morph their configuration to suit both their needs and others, and employ interference coping and exploitation techniques to make more efficient use of the RF spectrum. The Spectrum Grand Challenge will develop the world's first large-scale spectrum testbed to test participants in realistic emulated conditions. The test conditions and qualification metrics developed will thoroughly vet solutions, and ultimately serve as the basis for certification of an envisioned new class of shared spectrum technology which does not rely on exclusive use of the spectrum. This program complements spectrum access and wireless communications work in PE 0603760E, Project CCC-02. FY 2016 Plans: - Define Spectrum Grand Challenge rules governing eligibility as well how the competition will be conducted and scored. FY 2017 Plans: - Design and build out large-scale spectrum testbed for use in the preliminary competition of the Spectrum Grand Challenge. - Hold qualifying event to select field of participants. - Hold preliminary competition in an emulated RF environment using spectrum sharing testbed.				
Accomplishments/Planned Programs Subtotals		32.437	38.494	42.459
C. Other Program Funding Summary (\$ in Millions)				
N/A				
Remarks				
D. Acquisition Strategy				
N/A				
E. Performance Metrics				
Specific programmatic performance metrics are listed above in the program accomplishments and plans section.				

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency									Date: February 2016			
Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY				Project (Number/Name) IT-03 / INFORMATION ASSURANCE AND SURVIVABILITY			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
IT-03: INFORMATION ASSURANCE AND SURVIVABILITY	-	170.959	202.252	255.137	-	255.137	257.172	258.028	258.362	258.923	-	-
A. Mission Description and Budget Item Justification												
The Information Assurance and Survivability project is developing the core computing and networking technologies required to protect DoD's information, information infrastructure, and mission-critical information systems. The technologies will provide cost-effective security and survivability solutions that enable information systems to operate correctly and continuously while under attack and to be rapidly recovered/reconstituted in the aftermath of an attack. Technologies developed by this project will benefit other projects within this program element as well as projects in the Command, Control, and Communications program element (PE 0603760E), the Network-Centric Warfare Technology program element (PE 0603766E), the Sensor Technology program element (PE 0603767E), and other projects that require secure, survivable, network-centric information systems.												
B. Accomplishments/Planned Programs (\$ in Millions)									FY 2015	FY 2016	FY 2017	
Title: Edge-Directed Cyber Technologies for Reliable Mission Communication (EdgeCT)									11.500	22.000	29.938	
Description: The Edge-Directed Cyber Technologies for Reliable Mission Communication (EdgeCT) program is developing technologies to enable reliable communications for military forces that operate in the presence of disrupted, degraded or denied wide-area networks. The program is creating algorithms and software prototypes for use exclusively at the network edge, specifically, on end hosts and/or on proxy servers (middleboxes) fronting groups of such end hosts within a user enclave. EdgeCT systems will sense and respond rapidly to network failures and attacks by dynamically adapting protocols utilized to exchange packets among these hosts, thereby implementing fight-through strategies that restore networked communication. This will enable highly reliable networked communication for the military in the face of a wide variety of common network failure modes as well as cyber attacks against network infrastructure. EdgeCT technologies will be developed in collaboration with and transitioned to operational commands.												
FY 2015 Accomplishments:												
- Formulated a distributed architecture for reliable communications over high-speed wide-area networks that have been degraded by cyber attack, misconfiguration, or hardware/software failure.												
- Introduced techniques to sense and respond rapidly to network failures and attacks by dynamically adapting protocols utilized to exchange packets among hosts.												
- Created an initial wide-area network testbed enabling joint experimentation and demonstration of components and systems among program performers.												
FY 2016 Plans:												

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Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY		Project (Number/Name) IT-03 / INFORMATION ASSURANCE AND SURVIVABILITY	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
- Develop fight-through strategies that rapidly restore networked communication in the face of a wide variety of common network failure modes as well as cyber attacks against network infrastructure. - Demonstrate performance at the component and subsystem levels, to include real-time network analytics, holistic decision systems, and dynamically configurable protocol stacks. - Assess EdgeCT component and system designs for potential weaknesses, vulnerabilities, and countermeasures associated with cyber attacks against network infrastructure, or against EdgeCT systems themselves. - Initiate development of software prototypes suitable for laboratory experimentation with operational commands. - Explore modes of user interaction and system concepts of operation with one or more operational commands and bring software prototypes to an initial field experiment in collaboration with an operational command. FY 2017 Plans: - Demonstrate and evaluate system prototypes against program metrics to verify adequate performance for cumulative network utility, recovery time, and network overhead. - Increase the number of enclaves and total application data flows that can be accommodated during real-time operation. - Incorporate military applications, such as Command and Control (C2) software systems, into system demonstrations. - Extend usage and testing scenarios to include multiple forms of simultaneous failures and cyber attacks within the wide area network.					
Title: Cyber Fault-tolerant Attack Recovery (CFAR) Description: The Cyber Fault-tolerant Attack Recovery (CFAR) program is developing novel architectures to achieve cyber fault-tolerance with commodity computing technologies. Current approaches to handling cyber-induced faults in mission-critical systems are inadequate, as perimeter defenses wrapped around vulnerable monocultures do not scale, while zero-day exploits evade signature-based defenses. The proliferation of processing cores in multi-core central processing units provides the opportunity to adapt fault-tolerant architectures proven in aerospace applications to mission-critical, embedded, and real-time computing systems. The CFAR program will combine techniques for detecting differences across functionally replicated systems with novel variants that guarantee differences in behavior under attack. The resulting CFAR-enabled computing systems will quickly detect deviations in processing elements at attack onset and rapidly reboot to restore affected services. FY 2015 Accomplishments: - Formulated a novel architecture that can achieve cyber fault-tolerance with commodity computing technologies without requiring changes to the system concept of operations. - Developed initial techniques for detecting differences across functionally replicated systems. - Developed initial techniques for producing novel compiled software variants that behave differently under attack. FY 2016 Plans:			10.500	20.149	27.494

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY		Project (Number/Name) IT-03 / INFORMATION ASSURANCE AND SURVIVABILITY	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
- Demonstrate functionally replicated systems and novel variants that provide performance close to optimal and exhibit sufficient variability to guarantee differences in behavior under attack. - Implement and test techniques for quickly detecting differences across replicated systems. - Implement and evaluate alternative architectures for achieving cyber fault-tolerance for mission-critical military applications with commodity computing technologies. - Work with potential transition sponsors to evaluate military computing systems as candidates for technology refresh with CFAR technologies. FY 2017 Plans: - Create variants from binary code, which will enable the technology to protect systems for which source code is not readily available. - Develop methods to produce mathematical proofs of semantic equivalence across variants, which will contribute to assurance cases that systems protected with CFAR technology behave identically to the original unprotected systems. - Develop robust cyber fault-tolerant models that, unlike conventional approaches to physical fault tolerance, handle the highly correlated and frequent faults that may result from a cyber-attack. - Demonstrate proof-of-concept on a representative mission system, showing that the system behaves identically to the original while providing protection and rapid recovery from cyber attacks.					
Title: Supply Chain Hardware Integrity for Electronics Defense (SHIELD) Description: Counterfeit electronic components compromise business as well as defense systems, and pose a threat to the integrity and reliability of DoD systems. Detection of counterfeit components by current means is expensive, time-consuming, and of limited effectiveness. Maintaining complete control of the supply chain using administrative controls incurs substantial costs and has exhibited limited effectiveness. Current methods of detection involve a wide variety of techniques ranging from functional testing to physical inspections which may still miss certain classes of counterfeits. There have also been attempts by the semiconductor market to protect electronic components through the use of technology embedded in the component or its packaging. However, most of these methods are specific to a manufacturer's component and as such address only those issues critical to that manufacturer. Some methods can be circumvented, or require slow, expensive, off-site forensic analysis to verify authenticity. The Supply Chain Hardware Integrity for Electronics Defense (SHIELD) program will develop a technology capable of confirming, at any time and place, the authenticity of trusted parts, even after they have transited a complex global supply chain. SHIELD will prevent counterfeit component substitution by incorporating a small, inexpensive additional silicon chip ("dielet") within the Integrated Circuit (IC) package. The dielet will provide a unique and encrypted ID as well as anti-tamper features. The			17.750	21.000	24.500

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Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY		Project (Number/Name) IT-03 / INFORMATION ASSURANCE AND SURVIVABILITY	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
microscopic-size dielet embedded in the electronic component packaging will enable verification of a chip's identity from very close proximity.					
FY 2015 Accomplishments: - Refined design specifications and technical requirements for the SHIELD dielet, including Advanced Encryption Standard counter with Cipher Block Chaining Message Authentication Code (AES CCM) as the target encryption protocol. - Developed behavioral models for dielet power and communications to support preliminary design efforts. - Manufactured "surrogate" dielets with the dimensions and form factor of the SHIELD design for performers to develop package insertion methods and fragility testing. - Designed and manufactured hardware test sites to demonstrate proof of concept for key dielet technologies (sensors, power, communications, encryption, dielet fragility).					
FY 2016 Plans: - Refine designs based on measured results from test site hardware. Scale proof-of-concept work done at less advanced design nodes to the 40 nanometer and 14 nanometer target design nodes for SHIELD. - Design and manufacture hardware test sites to demonstrate second pass improvements for key dielet technologies. - Develop transaction model for reader-to-dielet interrogation. - Select best-fit Phase 1 technologies for inclusion on Phase 2 dielet designs, based on validated hardware measurements and objective analysis of design compatibility. - Refine dielet singulation, test and insertion methodology and fragility design based on mechanical testing of surrogate dielets.					
FY 2017 Plans: - Design and manufacture prototype SHIELD dielets, integrating best-fit technologies selected during Phase 1. - Implement dielet singulation method for wafers after manufacture. - Initiate functional and performance testing of manufactured SHIELD dielets. - Refine methods for dielet insertion into integrated circuit (IC) packages. - Build and test network appliance and server network for Phase 3 testing.					
Title: Brandeis* Description: *Previously Adaptable Information Access and Control (AIAC) The Brandeis program is creating the capability to dynamically, flexibly, and securely share information while ensuring that private data may be used only for its intended purpose and no other. In the civilian sphere, there is a recognized need for technologies that enable the sharing of information between commercial entities and U.S. government agencies. Similarly, the U.S. military is increasingly involved in operations that require highly selective sharing of data with a heterogeneous mix of allies, coalition			7.593	17.600	25.000

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602303E / <i>INFORMATION & COMMUNICATIONS TECHNOLOGY</i>		Project (Number/Name) IT-03 / <i>INFORMATION ASSURANCE AND SURVIVABILITY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
partners, and other stakeholders. The Brandeis program will develop the technical means to protect the private and proprietary information of individuals and enterprises. Brandeis will break the tension between (a) maintaining privacy and (b) being able to tap into the huge value of data. Rather than having to balance between them, Brandeis aims to build a third option: enabling safe and predictable sharing of data in which privacy is preserved. The Brandeis program is timely due to recent progress on techniques such as homomorphic encryption, secure multiparty computation, and differential privacy. To facilitate deployment, Brandeis technologies will be designed to work with the virtualization, cloud computing, and software-defined networking technologies now widely used in both civilian and military environments. FY 2015 Accomplishments: - Formulated technical approaches to data privacy through secure multiparty computation, secure database queries, differential privacy and remote attestation of protected computing environments. - Identified canonical privacy use cases on which to evaluate candidate privacy technologies. - Conceptualized prototype evaluation platforms and metrics/analysis tools on which privacy technologies can be tested and metrics computed to quantify the privacy benefits. FY 2016 Plans: - Implement secure multiparty computation, secure database queries, differential privacy and remote attestation techniques in initial prototypes suitable for integration on commodity cloud infrastructures. - Develop prototype evaluation platform and metrics/analysis tools on which privacy technologies can be tested and metrics computed. - Initiate quantification of privacy benefits of privacy technologies in the context of canonical individual and enterprise privacy use cases. FY 2017 Plans: - Optimize privacy prototypes that implement secure multiparty computation, secure database queries, differential privacy and remote attestation techniques and test on enterprise networks. - Quantify privacy benefits and the costs in terms of computational overhead and latency. - Perform detailed studies of the security implications of the techniques in terms of confidentiality, integrity, and availability of private information. - Initiate transition of techniques through integration on commercial, coalition partner, and military enterprise networks.					
Title: Rapid Attack Detection, Isolation and Characterization Systems (RADICS)*			7.525	17.513	24.500
Description: *Previously Protecting Cyber Physical Infrastructure					

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602303E / <i>INFORMATION & COMMUNICATIONS TECHNOLOGY</i>		Project (Number/Name) IT-03 / <i>INFORMATION ASSURANCE AND SURVIVABILITY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
The Rapid Attack Detection, Isolation and Characterization Systems (RADICS) program will create new technologies for maintaining the availability and integrity of critical U.S. cyber-physical infrastructure. This is a national security issue due to the near-ubiquitous use of computers to monitor and control U.S. civilian and military critical infrastructure such as electric power. RADICS will develop technologies to monitor heterogeneous distributed control system networks, detect anomalies that require rapid assessment, isolate compromised system elements, characterize attacks in real time, mitigate sensor spoofing and denial of service attacks, and restore services. Hardware-in-the-loop simulation techniques will be developed to enable the discovery of emergent vulnerabilities and the development and optimization of mitigation, restoration, and reconstitution strategies applicable to the power grid. This will include understanding the potential role of electric power markets and smart grid technologies in propagating or damping power grid anomalies. RADICS technologies will transition to military installations and commercial industry. FY 2015 Accomplishments: - Formulated resilient architectures for real-time monitoring, analysis, and assessment of distributed industrial control systems and physical infrastructure. - Investigated rapid re-provisioning techniques to quickly re-deploy firmware and operating system images to restore compromised devices back to a pristine, known state of operation. FY 2016 Plans: - Create a hardware-in-the-loop simulation capability to enable the discovery of emergent vulnerabilities and the development and optimization of mitigation strategies applicable to the U.S. power grid. - Develop technologies to monitor heterogeneous distributed industrial control system networks, detect anomalies that require rapid assessment, mitigate sensor spoofing and denial of service attacks, and restore services. - Extend simulation capabilities to understand the potential role of electric power markets in propagating or damping power grid anomalies. - Develop techniques that use organic sensors, remote instrumentation, and other sources of cyber situation awareness information to continuously optimize cyber defenses. FY 2017 Plans: - Validate emulations of embedded industrial control devices for development, test and evaluation of defensive cyber measures. - Explore techniques to enable validated dynamic simulations of cascading faults across large sections of a power grid. - Develop the means to produce a robust, multi-source time base with sufficient accuracy to enable continued operation of critical infrastructure in the event of a disruption of GPS signals. - Develop defense mechanisms for supervisory control and data acquisition systems that are subject to systematic/malicious attack in addition to random perturbations/failures.					
Title: High Assurance Cyber Military Systems			24.000	27.690	17.500

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY		Project (Number/Name) IT-03 / INFORMATION ASSURANCE AND SURVIVABILITY	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
Description: The High Assurance Cyber Military Systems (HACMS) program is developing and demonstrating technologies to secure mission-critical embedded computing systems. The DoD is making increasing use of networked computing in systems such as military vehicles, weapon systems, ground sensors, smartphones, and other communication devices. This dependence makes it critically important that the embedded operating system provides high levels of inherent assurance. This operating system must also integrate the computational, physical, and networking elements of the system while running on a processor with very limited size, weight, and power. Consequently, it can only devote a limited share of its computational resources to security while satisfying hard real-time constraints. Recent advances in program synthesis, formal verification techniques, low-level and domain-specific programming languages, and operating systems mean that fully verified operating systems for embedded devices may be within reach at reasonable costs. The program will develop, mature, and integrate these technologies to produce an embedded computing platform that provides a high level of assurance for mission-critical military applications. FY 2015 Accomplishments: - Formally verified full functional correctness for the extended core operating system and the automatically synthesized control systems for selected vehicles. - Demonstrated required security properties that follow from correctness for the extended core operating system and the automatically synthesized control systems. - Performed static and dynamic assessments after modifications were made on militarily-relevant vehicles to evaluate the effectiveness of the synthesis and formal methods tools. - Conducted a field test of a HACMS hardened operating system integrated in a helicopter mission computer during which live cyber attacks on unsecured applications were contained. FY 2016 Plans: - Apply an architecture-based approach to high-assurance system development to develop a large fraction of the software for a two-processor open-source quadcopter, a helicopter, an unmanned wheeled robot, and a military transport vehicle. - Demonstrate machine-tracked assurance cases for system-wide security properties on targeted vehicles. - Increase the level of automation of proof generation in theorem provers. - Evaluate the effectiveness of approaches by conducting penetration-testing exercises on the targeted vehicles. FY 2017 Plans: - Develop techniques for ensuring the predictable composability of adaptively assembled systems. - Formulate assurance cases for complex mission critical systems that are comprised of multiple interacting components. - Develop formal methods approaches to enable predictable system design at scale. - Evaluate the effectiveness of the formal methods approaches by conducting penetration-testing exercises.					
Title: Vetting Commodity Computing Systems for the DoD (VET)			21.987	22.625	18.019

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY	Project (Number/Name) IT-03 / INFORMATION ASSURANCE AND SURVIVABILITY		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Description: The Vetting Commodity Computing Systems for the DoD (VET) program is developing tools and methods to uncover backdoors and other hidden malicious functionality in the software and firmware on commodity IT devices. The international supply chain that produces the computer workstations, routers, printers, and mobile devices on which DoD depends provides many opportunities for our adversaries to insert hidden malicious functionality. VET technologies will detect hidden malicious functionality and also enable the detection of software and firmware defects and vulnerabilities that can facilitate adversary attack. FY 2015 Accomplishments: - Improved the effectiveness of prototype tools, in particular by reducing the rates of false alarms and missed detections, through further competitive engagements. - Expanded the set of challenge programs to explore more complex forms of malicious hidden functionality including race conditions, information leakage, and defective encryption. - Replaced initial experimental platforms with more complex devices that are more operationally representative. FY 2016 Plans: - Measure probabilities of false- and missed-detection and human analysis time to identify new techniques that are likely candidates for integration into an end-to-end DoD vetting application. - Initiate development of an integrated vetting application that incorporates the most promising new techniques and scales to problems of operationally relevant size. - Conduct an integrated end-to-end software/firmware-vetting technology demonstration relevant to potential transition partners. FY 2017 Plans: - Run comparative performance evaluations between program-developed vetting tools and commercially available tools. - Engage in experiments and pilot deployments of prototype tools with transition partners on software of interest to DoD. - Based on user feedback, make improvements to prototypes to enhance usability in the context of vetting software for DoD.				
Title: Cyber Grand Challenge (CGC) Description: The Cyber Grand Challenge (CGC) program will create automated defenses that can identify and respond to cyber attacks more rapidly than human operators. CGC technology will monitor defended software and networks during operations, reason about flawed software, formulate effective defenses, and deploy defenses automatically. Technologies to be developed and integrated may include anomaly detection, Monte Carlo input generation, case-based reasoning, heuristics, game theory, and stochastic optimization. The CGC capability is needed because highly-scripted, distributed cyber attacks exhibit speed, complexity, and scale that exceed the capability of human cyber defenders to respond in a timely manner. DARPA will incentivize competition through a Grand Challenge in which CGC technologies compete head-to-head. Initial funding for this effort was		6.233	11.329	11.000

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY		Project (Number/Name) IT-03 / INFORMATION ASSURANCE AND SURVIVABILITY	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
provided in Project IT-05. Additional funding is being provided in IT-03 to enable the creation of the more robust competition infrastructure necessary to accommodate the large number of competitors.					
FY 2015 Accomplishments: - Created the robust competition infrastructure required to accommodate the large number of competitors.					
FY 2016 Plans: - Conduct world's first automated computer security contest: Cyber Grand Challenge Final Event. - Release event results as cyber research corpus to measure and challenge future automated cyber capabilities.					
FY 2017 Plans: - Use the lessons learned from the (first) Cyber Grand Challenge Final Event to design a follow-on competition in which competitor systems compete directly against experts. - Benchmark and baseline the abilities of expert reverse engineers to guide the creation of a machine-vs-expert competition corpus. - Initiate development of a competition infrastructure that allows for distributed machine-vs-expert tournament play.					
Title: Extreme Distributed Denial of Service Defense (XD3)			-	14.996	26.500
Description: Building upon work in the Mission-oriented Resilient Clouds (MRC) program, the Extreme Distributed Denial of Service Defense (XD3) program will develop new computer networking architectures better able to deter, detect, and overcome distributed denial of service (DDoS) attacks. DDoS attacks include not only high-volume flooding attacks of hundreds of gigabits per second, but more subtle low-volume attacks that evade traditional intrusion detection systems while causing exhaustion of server processor and memory capacity. These attacks will likely accelerate as the Internet of Things (IoT) expands to new classes of devices that in many cases will be deployed with inadequate security controls: attackers will incorporate poorly defended IoT devices in their botnets. XD3 will develop defensive architectures that use maneuver, deception, dispersion, and on-host adaptation to increase adversary work factors, boost resilience of mission critical services such as command and control, and ultimately thwart DDoS attacks.					
FY 2016 Plans: - Formulate architectures and algorithms that enable physical and/or logical dispersion of likely DDoS targets (e.g., servers and cloud computing facilities) to complicate the location and targeting of these cyber resources by DDoS attackers. - Develop network maneuver and deception techniques that increase adversary work factors in target development, attack planning, and execution.					

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY	Project (Number/Name) IT-03 / INFORMATION ASSURANCE AND SURVIVABILITY		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Devise means for enabling servers and similar DDoS targets to sense the presence of DDoS attacks (especially low-volume attacks) and to adapt their operation in real time to mitigate the attack while preserving performance for legitimate users. FY 2017 Plans: - Develop testing capabilities to support iterative experimentation and demonstration of prototypes. - Implement and integrate network dispersion, maneuver, and deception techniques in prototype systems that increase adversary work factors in target development, attack planning, and execution. - Perform system-level demonstrations and subject systems to critical assessments to pinpoint design weaknesses and vulnerabilities. - Conduct military field exercises in collaboration with transition partners to elicit feedback on XD3 features, capabilities, and concepts of operation.				
Title: Leveraging the Analog Domain for Security (LADS) Description: The Leveraging the Analog Domain for Security (LADS) program, building upon the Vetting Commodity Computing Systems for the DoD (VET) program, will develop and demonstrate techniques for defending information systems using side channel signals such as radio frequency and acoustic emissions, power consumption, heat generation, differential fault analysis, and timing-based effects. LADS augments standard cybersecurity approaches, which focus on digital effects/phenomena, with analog techniques. LADS will enable defenders to detect cyber attacks by sensing changes in the analog emissions of computing components, devices, and systems, greatly complicating the task of adversaries who wish to remain covert. FY 2016 Plans: - Formulate approaches for measuring side channel signals such as radio frequency and acoustic emissions, power consumption, heat generation, differential fault analysis, and timing-based effects in noisy environments. - Investigate rule-based and statistical classification techniques for discriminating side channel signals emitted from computing components, devices, and systems operating in compromised/faulty states from those operating in secure/correct states. - Propose approaches for predicting side channel emissions given knowledge of the computing system hardware and executed code. FY 2017 Plans: - Develop quantitative models for side channel signals emitted from systems operating in secure/correct states and from systems operating in compromised/faulty states and validate the models through laboratory measurements. - Assess the practicality of initial techniques for discriminating side channel signals emitted from systems operating in compromised/faulty states from those operating in secure/correct states by computing receiver operating characteristics (probability of detection versus probability of false alarm).		-	10.000	19.000

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY	Project (Number/Name) IT-03 / INFORMATION ASSURANCE AND SURVIVABILITY	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Develop statistical models for side channel emissions given imprecise/probabilistic knowledge of the executed code.			FY 2017
Title: Plan X Description: The Plan X program is developing technologies to enable comprehensive awareness and understanding of the cyber battlespace as required for visualizing, planning, and executing military cyber warfare operations. This includes intelligence preparation of the cyber battlespace, indications and warning of adversary cyber actions, detection of cyber-attack onset, cyber-attacker identification, and cyber battle damage assessment. Plan X is creating new graphical interfaces that enable intuitive visualization of events on hosts and networks to aid in the planning and execution of cyber warfare. Plan X will extend operationally meaningful measures to project quantitatively the collateral damage of executed cyber warfare missions. Initial funding for this effort was provided in Project IT-05. Funding continues in IT-03 for testing and evaluation through participation in tactical level exercises and integrating the Plan X system into transition partner operating profiles. FY 2017 Plans: - Refine Plan X capabilities to provide operators with enhanced cyber situational awareness and to enable operators to execute cyber warfare missions with projections of cyber collateral damage. - Demonstrate capabilities in multiple military cyber exercises, such as Cyber Guard, Cyber Flag, and Red Flag. - Refine operator workflows and operational use cases based on exercise feedback. - Work with transition partners, such as U.S. Cyber Command (USCYBERCOM) and U.S. Army Cyber Command (ARCYBER), to integrate Plan X into current operating systems.		-	23.349
Title: System Security Integrated Through Hardware and software (SSITH) Description: System Security Integrated Through Hardware and software (SSITH) seeks to better protect DoD systems by exploring innovative approaches that combine hardware and software to provide enhanced system security. Traditional cybersecurity approaches have focused either on software or hardware, but rarely on an integration of both domains. By exploring integrated hardware/software solutions, SSITH will combine the efficiency and robustness of hardware with the flexibility and adaptability of software to provide security solutions that are resistant to attack and adaptive to new attack approaches. The program is based on the concept that co-design of hardware and software provides new modalities to protect electronic systems. The SSITH program will pursue several hardware/software approaches to enhancing electronic system security. First, the program will investigate new co-designed hardware/software architectures that are inherently more secure than current electronic systems. Second, the program will investigate hardware/software architectures that are flexible and can adapt to new system attack methods and vectors. Third, the program will examine methods to reduce the power/performance overhead required to implement novel and powerful protection methods recently conceived in the security community.		-	8.337

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY		Project (Number/Name) IT-03 / INFORMATION ASSURANCE AND SURVIVABILITY	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
FY 2017 Plans: - Define new hardware/software architectures that implement flexible and robust protection against external attack. - Utilize modeling and simulation approaches to determine the expected improvement in protection of the new hardware/software architectures relative to software only and hardware only approaches.					
Title: Mission-oriented Resilient Clouds (MRC) Description: The Mission-oriented Resilient Clouds (MRC) program is creating technologies to enable cloud computing systems to survive and operate through cyber attacks. Vulnerabilities found in current standalone and networked systems can be amplified in cloud computing environments. MRC is addressing this risk by creating advanced network protocols and new approaches to computing in potentially compromised distributed environments. Particular attention is focused on adapting defenses and allocating resources dynamically in response to attacks and compromises. MRC will result in new approaches to measure trust, reach consensus in compromised environments, and allocate resources in response to current threats and computational requirements. MRC will develop new verification and control techniques for networks embedded in clouds that must function reliably in complex adversarial environments.			15.892	8.750	-
FY 2015 Accomplishments: - Demonstrated automated construction of diverse, redundant network flow paths that maximize communication resilience in clouds. - Evaluated and measured the scalability and resilience of a high-assurance cloud computing application development library in terms of number of concurrent replicas supported and volume of data handled. - Developed and demonstrated hardened network services through fine-grained memory access controls that determine what valid memory addresses are read or written to by each instruction in a program. - Demonstrated concurrent optimization of computing resources and network bandwidth to achieve significant reduction in network load with no performance loss. - Inserted and evaluated multiple MRC technologies into U.S. Pacific Command (USPACOM) distributed computing environments. - Assessed technologies with Defense Information Systems Agency (DISA) to facilitate transitions into DoD networks and clouds.					
FY 2016 Plans: - Demonstrate correct, disruption-free upgrading of software defined networking controllers in live networks. - Complete transition of one or more technologies into operational use by USPACOM and DISA. - Transition secured version of multi-UAV control software to Air Force Research Laboratory (AFRL).					
Title: Active Cyber Defense (ACD)			13.828	8.600	-

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY	Project (Number/Name) IT-03 / INFORMATION ASSURANCE AND SURVIVABILITY		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Description: The Active Cyber Defense (ACD) program will enable DoD cyber operators to fully leverage our inherent home field advantage when defending the DoD cyber battlespace. In the cyber environment, defenders have detailed knowledge of, and unlimited access to, the system resources that attackers wish to gain. The ACD program will exploit emerging technologies to facilitate the conduct of defensive operations that involve immediate and direct engagement between DoD cyber operators and sophisticated cyber adversaries. Through these active engagements, DoD cyber defenders will be able to more readily disrupt, counter, and neutralize adversary cyber tradecraft in real time. Moreover, ACD-facilitated operations should cause adversaries to be more cautious and increase their work factor by limiting success from their efforts. FY 2015 Accomplishments: - Completed development of system components. - Performed a limited capability demonstration at CYBERFLAG 15-1 training exercise by successfully defending a targeted network enclave from attack. - Began integration of technologies into complete prototype platforms. - Tested integrated capabilities in collaboration with Director, Operational Test and Evaluation (DOT&E). FY 2016 Plans: - Complete integration of system platforms and demonstrate capabilities to transition partners. - Perform final test and evaluation of integrated capabilities and obtain approval for operational deployment. - Support initial operational fielding of capability to facilitate transition to DoD cyber operators.				
Title: Rapid Software Development using Binary Components (RAPID) Description: The Rapid Software Development using Binary Components (RAPID) program developed a system to identify and extract software components for reuse in new applications. The DoD has critical applications that must be ported to future operating systems. In many cases, the application source code is no longer available requiring these applications to continue to run on insecure and outdated operating systems, potentially impacting operations. Advanced technology development for the program was budgeted in PE 0603760E, Project CCC-04. FY 2015 Accomplishments: - Developed new software component reuse capabilities to extend application performance to a wider range of realistic scenarios and enable an expanded concept of operations. - Implemented new capabilities in modules designed to interoperate seamlessly with deployed RAPID prototype systems. - Integrated new modules into prototype RAPID systems deployed at transition partner sites and supported initial operations.		10.396	-	-
Title: Active Authentication		7.025	-	-

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Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY		Project (Number/Name) IT-03 / INFORMATION ASSURANCE AND SURVIVABILITY	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
Description: The Active Authentication program developed more effective user identification and authentication technologies. Current authentication approaches are typically based on long, complex passwords and incorporate no mechanism to verify that the user originally authenticated is the user still in control of the session. The Active Authentication program addressed these issues by focusing on the unique aspects of the individual (i.e., the cognitive fingerprint) through the use of software-based biometrics that continuously validate the identity of the user. Active Authentication integrated multiple biometric modalities to create an authentication system that is accurate, robust, and transparent to the user. FY 2015 Accomplishments: - Demonstrated multiple authentication biometrics suitable for deployment on desktop and mobile hardware for potential use by the DoD. - Prototyped an authentication platform suitable for use on desktop and mobile hardware in collaboration with potential transition sponsors. - Proved flexibility of the underlying prototype platform by creating an additional authentication platform suitable for DoD.					
Title: Anomaly Detection at Multiple Scales (ADAMS) Description: The Anomaly Detection at Multiple Scales (ADAMS) program developed and applied algorithms for detecting anomalous, threat-related behavior of systems, individuals, and groups over hours, days, months, and years. ADAMS developed flexible, scalable, and highly interactive approaches to extracting actionable information from information system log files, sensors, and other instrumentation. ADAMS integrated these anomaly detection algorithms to produce adaptable systems for timely insider threat detection. FY 2015 Accomplishments: - Developed techniques for representing end-user knowledge and feedback to ensure that the machine learning algorithms are working with the most effective features possible. - Demonstrated and quantified performance of algorithms in a series of controlled tests on blended synthetic/real data. - Hardened prototypes and installed these in operational environments for testing and evaluation.			7.000	-	-
Title: Clean-slate design of Resilient, Adaptive, Secure Hosts (CRASH) Description: The Clean-slate design of Resilient, Adaptive, Secure Hosts (CRASH) program developed cyber security technologies using the mechanisms of biological systems as inspiration for radically re-thinking basic hardware and system designs. Higher level organisms have two distinct immune systems: the innate system is fast and deadly but is only effective against a fixed set of pathogens; the adaptive system is slower but can learn to recognize novel pathogens. Similarly, CRASH developed mechanisms at the hardware and operating system level that eliminate known vulnerabilities exploited by attackers. However, because novel attacks will be developed, CRASH also developed software techniques that allow a computer system			6.730	-	-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY		Project (Number/Name) IT-03 / INFORMATION ASSURANCE AND SURVIVABILITY	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
to defend itself, to maintain its capabilities, and even heal itself. Finally, biological systems show that diversity is an effective population defense; CRASH developed techniques that make each computer system appear unique to the attacker and allow each system to change over time.					
FY 2015 Accomplishments: - Produced a hardened web server and browser that enable the creation of secure web applications from untrusted code. - Initiated two international standards submissions for securing web browsers and their communications. - Demonstrated policy-based application monitoring and hardware-assisted self-healing of multiple applications and hardware-based detection of malicious software. - Developed and demonstrated automated code randomization techniques to implement moving target defenses for software. - Developed and commercialized technology to detect hardware trojans in field programmable gate array (FPGA) components and provide host protection for embedded devices, including routers, printers and Voice over Internet Protocol (VoIP) phones.					
Title: Integrated Cyber Analysis System (ICAS) Description: The Integrated Cyber Analysis System (ICAS) program developed techniques to automatically discover probes, intrusions, and persistent attacks on enterprise networks. At present, discovering the actions of capable adversaries requires painstaking forensic analysis of numerous system logs by highly skilled security analysts and system administrators. ICAS technologies facilitate the correlation of interactions and behavior patterns across all system data sources and thereby rapidly uncover aberrant events and detect system compromise. This includes technologies for automatically representing, indexing, and reasoning over diverse, distributed, security-related data and system files. FY 2015 Accomplishments: - Developed and implemented algorithms for automatically identifying and quantifying specific security risks on enterprise networks. - Conducted initial technology demonstrations including automatic indexing of data sources, common language integration, and reasoning across federated databases. - Integrated, evaluated, and optimized algorithms via testing against attacks/persistent threats provided by transition partners. - Completed fully functional beta versions of the applications with operational stability suitable for testing at transition partner locations.			3.000	-	-
Accomplishments/Planned Programs Subtotals			170.959	202.252	255.137
C. Other Program Funding Summary (\$ in Millions) N/A					

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / <i>INFORMATION & COMMUNICATIONS TECHNOLOGY</i>	Project (Number/Name) IT-03 / <i>INFORMATION ASSURANCE AND SURVIVABILITY</i>
C. Other Program Funding Summary (\$ in Millions) Remarks D. Acquisition Strategy N/A E. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.		

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY				Project (Number/Name) IT-04 / LANGUAGE UNDERSTANDING AND SYMBIOTIC AUTOMATION			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
IT-04: LANGUAGE UNDERSTANDING AND SYMBIOTIC AUTOMATION	-	48.636	60.948	56.039	-	56.039	41.574	41.856	41.755	36.755	-	-

A. Mission Description and Budget Item Justification

The Language Understanding and Symbiotic Automation project develops technologies to enable computing systems to understand human speech and extract information contained in diverse media; to learn, reason and apply knowledge gained through experience; and to respond intelligently to new and unforeseen events. Enabling computing systems in this manner is of critical importance because sensor, information, and communication systems generate data at rates beyond which humans can assimilate, understand, and act. Incorporating these technologies in military systems will enable warfighters to make better decisions in complex, time-critical, battlefield environments; and allow intelligence analysts to make sense of massive, incomplete, and contradictory information; and unmanned systems to operate safely with high degrees of autonomy.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Low Resource Languages for Emergent Incidents (LORELEI)	17.875	22.225	28.620
Description: The Low Resource Languages for Emergent Incidents (LORELEI) program is developing the technology to rapidly field machine translation capabilities for low-resource foreign languages. The United States military operates globally and frequently encounters low-resource languages, i.e., languages for which few linguists are available and no automated human language technology capability exists. Historically, exploiting foreign language materials required protracted effort, and current systems rely on huge, manually-translated, manually-transcribed, or manually-annotated data sets. As a result, systems currently exist only for languages in widespread use and in high demand. LORELEI will take a different approach by leveraging language-universal resources, projecting from related-language resources, and fully exploiting a broad range of language-specific resources. These capabilities will be exercised to rapidly provide situational awareness based on information from any language in support of emergent missions such as humanitarian assistance/disaster relief, terrorist attack response, peacekeeping, and infectious disease response.			
FY 2015 Accomplishments: - Explored techniques for optimizing combinations of existing resources to eliminate reliance on large parallel corpora. - Proved viability of techniques to identify and link mentions of entities from text in a low-resource language to a knowledge base. - Developed methodologies for generating morphological variants of a word and for clustering entity mentions.			
FY 2016 Plans: - Develop initial techniques for quantifying the linguistic similarity of language usage in diverse documents and media. - Develop algorithms to exploit the universal properties of languages when rapidly ramping up for a low-resource language.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602303E / <i>INFORMATION & COMMUNICATIONS TECHNOLOGY</i>		Project (Number/Name) IT-04 / <i>LANGUAGE UNDERSTANDING AND SYMBIOTIC AUTOMATION</i>	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
- Develop semantic techniques for identifying the common topics, themes, and sentiment in speech and text in diverse foreign languages. - Collect, generate, and annotate data for an initial set of resources in typologically representative medium-resource languages. - Create a baseline toolkit to rapidly develop an initial situational awareness capability given a new low-resource language document collection. FY 2017 Plans: - Develop means to determine opinions and beliefs in low-resource languages. - Construct an integrated system employing multiple algorithms for low-resource language analysis. - Develop the user interface platform that will provide native speaker information to the analysis platform and provide query-driven information to the users. - Evaluate the performance of the analysis algorithms on two new languages and measure progress on the languages evaluated in the previous year. - Work with end users to utilize and evaluate the interface platform.					
Title: Deep Exploration and Filtering of Text (DEFT) Description: The Deep Exploration and Filtering of Text (DEFT) program is developing language technology to enable automated extraction, processing, and inference of information from text in operationally relevant application domains. A key DEFT emphasis is to determine explicit and implicit meaning in text through probabilistic inference, anomaly detection, and other techniques. To accomplish this, DEFT will develop and apply formal representations for basic facts, spatial, temporal, and associative relationships, causal and process knowledge, textually entailed information, and derived relationships and correlated actions/ events. DEFT inputs may be in English or in a foreign language and sources may be reports, messages, or other documents. DEFT will extract knowledge at scale for open source intelligence and threat analysis. Planned transition partners include the intelligence community and operational commands. FY 2015 Accomplishments: - Developed technology for extracting belief, sentiment and intent, for representing geo-spatial features and temporal events, and for inference from a set of documents. - Integrated multiple complementary algorithms into a comprehensive and consistent functional suite to support end-user workflows and problems. - Focused algorithm development on knowledge base representation in preparation for embedding algorithms in workflows to enable reasoning and downstream analysis. - Initiated work to adapt algorithms to specific foreign languages. - Conducted performance evaluations on event representation and other aspects of knowledge base population.			23.933	30.223	17.419

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / <i>INFORMATION & COMMUNICATIONS TECHNOLOGY</i>	Project (Number/Name) IT-04 / <i>LANGUAGE UNDERSTANDING AND SYMBIOTIC AUTOMATION</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Transitioned multiple algorithms and conducted effectiveness assessments at multiple end-user sites. FY 2016 Plans: - Improve algorithm performance on current functions and expand to new functions such as extending currently single-document algorithms to function across multiple documents. - Improve the discovery of different ways in which names of people and other entities are expressed across multiple documents, and develop techniques for linking them together. - Merge and optimize combined output of algorithms focused on different tasks such as belief and sentiment extraction, event argument and attribute identification, and relation mapping. - Develop methods for evaluating the effectiveness of various natural language processing algorithms in a multi-lingual environment, including evaluation of sentiment and belief analysis. - Transition an initial system-level prototype and additional component prototypes to end-user sites for effectiveness assessment. - Refine areas of focus based on results of transition site evaluations and open evaluation performance. FY 2017 Plans: - Develop algorithms to detect sub-events and identify their relationships to main events. - Evaluate the accuracy and effectiveness of language processing in specific foreign languages. - Develop algorithms to combine information from multiple language sources. - Transition a multi-lingual system-level prototype to end-user sites for effectiveness assessment.			
Title: Robust Automatic Transcription of Speech (RATS) Description: The Robust Automatic Transcription of Speech (RATS) program is developing robust speech processing techniques for conditions in which speech signals are degraded by distortion, reverberation, and/or competing conversation. Robust speech processing technologies enable soldiers to hear or read clear English versions of what is being said in their vicinity, despite a noisy or reverberant environment. Techniques of interest include speech activity detection, language identification, speaker identification, and keyword spotting. RATS technology is being developed and optimized on real world data in conjunction with several operational users. FY 2015 Accomplishments: - Developed new methods for field adaptations, which include lightly supervised and unsupervised adaptation of the algorithms to new channels and environments. - Developed methods for coping with extraneous signals found in field data. - Developed techniques to reduce the data required to adapt algorithms to new channels from hours to minutes.		6.828	8.500
			-

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Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY		Project (Number/Name) IT-04 / LANGUAGE UNDERSTANDING AND SYMBIOTIC AUTOMATION	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
- Produced a software integrated platform with a set of Application Programming Interfaces (APIs) and Graphical User Interfaces (GUIs) to be inserted at DoD and intelligence community partner sites and tested in the working environment of the partners. FY 2016 Plans: - Develop, integrate and test techniques to deal with multiple speakers and overlapping speaker channels. - Collect and annotate additional field collected data. - Develop unified API and interface to support multiple tactical integration platforms. - Integrate technologies in transition partner platforms, adjusting systems to fit partner needs. - Evaluate technologies on specialized operational scenarios.					
Title: Understanding Machine Intelligence (UMI) Description: The Understanding Machine Intelligence (UMI) program will develop techniques that enable artificial intelligence (AI) systems to better support users through transparent operation. If current trends continue, future U.S. military autonomous systems will need to perform increasingly complex and sensitive missions. AI will be critical to such autonomous systems, but in order for developers, users, and senior leaders to feel confident enough to deploy and use AI-enabled systems, they must operate with high degrees of transparency, reliability, predictability, and safety. UMI will develop AI technologies that support transparency by providing supporting rationale and logic sequences that establish the basis for and reliability of outputs. In addition, efforts will be made to develop a mathematically rigorous virtual stability theory for AI-enabled systems analogous to the (conventional) stability theory developed for dynamical systems (solutions to systems of differential equations). Such a virtual stability theory will enable the creation of feedback mechanisms that flag, interrupt, and modify anomalous outputs and behaviors to ensure safe, predictable operation. UMI implementations will be developed and demonstrated in next-generation decision-support and autonomous systems. This program was previously funded in PE 0602702E, Project TT-13. FY 2017 Plans: - Formulate approaches for AI systems to explain their behavior and clarify the basis for and reliability of outputs. - Develop automated drill-down techniques that provide users with logic/data that drives AI system outputs/behaviors. - Develop a mathematically rigorous virtual stability theory for AI-enabled logic systems analogous to the (conventional) stability theory developed for dynamical systems. - Propose a general technology for building systems with the ability to understand, explain, and modify their behavior.			-	-	10.000
Accomplishments/Planned Programs Subtotals			48.636	60.948	56.039
C. Other Program Funding Summary (\$ in Millions)					
N/A					

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / <i>INFORMATION & COMMUNICATIONS TECHNOLOGY</i>	Project (Number/Name) IT-04 / <i>LANGUAGE UNDERSTANDING AND SYMBIOTIC AUTOMATION</i>
C. Other Program Funding Summary (\$ in Millions)		
Remarks		
D. Acquisition Strategy N/A		
E. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.		

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY				Project (Number/Name) IT-05 / CYBER TECHNOLOGY			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
IT-05: CYBER TECHNOLOGY	-	63.891	39.664	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-
A. Mission Description and Budget Item Justification												
The Cyber Technology project develops technology to increase the security of military information systems and the effectiveness of cyber operations. Over the past decade the DoD has embraced net-centric warfare by integrating people, platforms, weapons, sensors, and decision aids. Adversaries seek to limit this force multiplier through cyber attacks intended to degrade, disrupt, or deny military computing, communications, and networking systems. Technologies developed under the Cyber Technology project will ensure DoD net-centric capabilities survive adversary cyber attacks and will enable new cyber-warfighting capabilities. Promising technologies will transition to system-level projects.												
B. Accomplishments/Planned Programs (\$ in Millions)									FY 2015	FY 2016	FY 2017	
Title: Plan X									38.161	29.800	-	
Description: The Plan X program is developing technologies to enable comprehensive awareness and understanding of the cyber battlespace as required for visualizing, planning, and executing military cyber warfare operations. This includes intelligence preparation of the cyber battlespace, indications and warning of adversary cyber actions, detection of cyber-attack onset, cyber-attacker identification, and cyber battle damage assessment. Plan X is creating new graphical interfaces that enable intuitive visualization of events on hosts and networks to aid in the planning and execution of cyber warfare. Plan X will extend operationally meaningful measures to project quantitatively the collateral damage of executed cyber warfare missions. Plan X funding continues in FY 2017 in Project IT-03.												
FY 2015 Accomplishments:												
- Created runtime environment and platforms capable of supporting a large scale user base, massive-scale deployments, resiliency to failure of any system component, and managed high ingest rates.												
- Demonstrated military network tactical situational awareness applications and use cases.												
- Released Plan X 1.0 system and field tested capabilities at Cyber Guard 2015.												
- Conducted field tests of computer network operations scenario development and training capabilities.												
- Planned transition to operational environments including understanding of transition partner networks and integration points.												
FY 2016 Plans:												
- Publish application store software development kit and integrate third party cyber capabilities.												
- Refine analytics features for battlespace, analysis of courses of action, and planning subsystems.												
- Adopt and integrate security access and use privileges, and demonstrate large-scale deployment of the end-to-end system with users in disparate locations.												

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / INFORMATION & COMMUNICATIONS TECHNOLOGY	Project (Number/Name) IT-05 / CYBER TECHNOLOGY		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Integrate with existing military command and control/intel systems to allow bidirectional flow of data to and from Plan X to provide visualization and insights into the cyber battlespace. - Release Plan X 2.0 system and field test capabilities at Cyber Flag 2016, and initiate technology transition with USCYBERCOM and Service components.				
Title: Cyber Grand Challenge (CGC) Description: The Cyber Grand Challenge (CGC) is creating automated defenses that can identify and respond to cyber attacks more rapidly than human operators. CGC technology will monitor defended software and networks during operations, reason about flawed software, formulate effective defenses, and deploy defenses automatically. Technologies to be developed and integrated may include anomaly detection, Monte Carlo input generation, case-based reasoning, heuristics, game theory, and stochastic optimization. The CGC capability is needed because highly-scripted, distributed cyber attacks exhibit speed, complexity, and scale that exceed the capability of human cyber defenders to respond in a timely manner. DARPA will incentivize competition through a Grand Challenge in which CGC technologies compete head-to-head. The CGC program is also funded in Project IT-03. FY 2015 Accomplishments: - Conducted mid-term qualification of finalist automated cyber technologies through competitive challenge. - Began second phase development of automated cyber defenders to allow real time in situ network defense decision-making. - Released first of two cyber research measurement and experimentation corpora with associated competition results. FY 2016 Plans: - Conduct world's first automated computer security contest: CGC Final Event. - Prepare automated systems for final competition via a multi-month series of audited trials. - Release final event results as cyber research corpus to measure and challenge future automated cyber capabilities.		16.832	9.864	-
Title: Crowd Sourced Formal Verification (CSFV) Description: The Crowd-Sourced Formal Verification (CSFV) program created technologies that enable crowd-sourced approaches to securing software systems through formal verification. Formal software verification is a rigorous method for proving that software has specified properties, but formal verification does not currently scale to the size of software found in modern weapon systems. CSFV enabled non-specialists to participate productively in the formal verification process by transforming formal verification problems into user-driven simulations that are intuitively understandable. FY 2015 Accomplishments: - Completed development of five new simulations. - Refined simulations to make them accessible to a large set of non-specialists.		8.898	-	-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / <i>INFORMATION & COMMUNICATIONS TECHNOLOGY</i>	Project (Number/Name) IT-05 / <i>CYBER TECHNOLOGY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Augmented simulations to handle large Java and C computer programs consisting of hundreds of thousands of lines of source code. - Enhanced public website to include these new simulations. - Assessed effectiveness of the new simulations on large-sized code targets.			
Accomplishments/Planned Programs Subtotals		63.891	39.664
C. Other Program Funding Summary (\$ in Millions) N/A Remarks D. Acquisition Strategy N/A E. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.			

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400: Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research					R-1 Program Element (Number/Name) PE 0602383E / BIOLOGICAL WARFARE DEFENSE							
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	42.447	24.265	21.250	-	21.250	11.014	13.469	14.346	14.346	-	-
BW-01: BIOLOGICAL WARFARE DEFENSE	-	42.447	24.265	21.250	-	21.250	11.014	13.469	14.346	14.346	-	-

A. Mission Description and Budget Item Justification

The Biological Warfare Defense project is budgeted in the Applied Research Budget Activity because its focus is on the underlying technologies associated with the detection, prevention, treatment and remediation of biological, chemical, and radionuclide threats.

Efforts to counter existing and emerging biological; chemical and radiological threats include countermeasures to stop the pathophysiologic processes that occur as a consequence of an attack; host immune response enhancers; medical diagnostics for the most virulent pathogens and their molecular mechanisms; collection of environmental trace constituents to support chemical mapping, tactical and strategic biological, chemical, and radiological sensors; and integrated defense systems. This program also includes development of a unique set of platform technologies and medical countermeasures synthesis that will dramatically decrease the timeline from military threat detection to countermeasure availability.

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	43.780	29.265	18.250	-	18.250
Current President's Budget	42.447	24.265	21.250	-	21.250
Total Adjustments	-1.333	-5.000	3.000	-	3.000
• Congressional General Reductions	0.000	-5.000			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	0.000	0.000			
• SBIR/STTR Transfer	-1.333	0.000			
• TotalOtherAdjustments	-	-	3.000	-	3.000

Change Summary Explanation

FY 2015: Decrease reflects the SBIR/STTR transfer.

FY 2016: Decrease reflects congressional reduction.

FY 2017: Increase reflects program repricing in Defense Against Mass Terror Threats.

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602383E / <i>BIOLOGICAL WARFARE DEFENSE</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Title: Medical Countermeasures		18.447	9.750	7.082
Description: To further develop an expedited medical countermeasure capability, emerging technologies will be integrated to address the safety and efficacy considerations in the risk/benefit package necessary to successfully counter naturally emerging or engineered biological warfare threats and new emerging chemical and radiological threats. These technologies will also be focused on reduction of time, risk, and costs associated with new therapeutic development. For example, this program will develop in vitro tissue constructs (IVTC) that will emulate human response to therapeutic compounds, thereby significantly reducing the cost and time for evaluating safety and efficacy of therapeutics. FY 2015 Accomplishments: - Demonstrated an expanded set of IVTCs able to reproduce the function of four human physiological systems. - Demonstrated an automated prototype system for monitoring the health and response of IVTCs to test compounds. - Designed and built additional modules that are compatible with the expanded set of IVTCs and enable the platform to sustain the integrated IVTCs for two weeks. - Demonstrated that the expanded set of four IVTCs individually respond and react to test compounds in a manner consistent with the known effects of those compounds on the corresponding human tissues. - Demonstrated that a modular arrangement of the expanded set of four IVTCs can be used to predict the absorption, distribution, metabolism, and elimination that the test compounds are known to exhibit in human physiological systems. FY 2016 Plans: - Demonstrate an expanded set of IVTCs able to reproduce the function of seven human physiological systems. - Design and build additional modules that are compatible with the expanded set of IVTCs and enable the platform to sustain the integrated IVTCs for three weeks. - Demonstrate that the expanded set of seven IVTCs individually respond and react to test compounds in a manner consistent with the known effects of those compounds on the corresponding human tissues. - Demonstrate that a modular arrangement of the expanded set of seven IVTCs can be used to predict the absorption, distribution, metabolism, and elimination that the test compounds are known to exhibit in human physiological systems. FY 2017 Plans: - Demonstrate an expanded set of IVTCs able to reproduce the function of ten human physiological systems. - Design and build additional modules that are compatible with the expanded set of IVTCs and enable the platform to sustain the integrated IVTCs for four weeks. - Demonstrate that the expanded set of ten IVTCs individually respond and react to test compounds in a manner consistent with the known effects of those compounds on the corresponding human tissues.				
Title: Defense Against Mass Terror Threats		24.000	14.515	14.168

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602383E / <i>BIOLOGICAL WARFARE DEFENSE</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Description: The objective of the Defense Against Mass Terror Threats program is to identify and develop technologies that have the potential to significantly improve U.S. ability to reduce the risk of mass casualties in the wake of a nuclear attack. Challenges in reducing U.S. vulnerability to a nuclear attack include monitoring radiation levels and exposure in urban areas and mitigating the lethal short and long term effects of ionizing radiation. A major goal of this program is to develop new sensors and sensing networks that can economically and reliably provide wide area monitoring of radionuclide signatures.				
FY 2015 Accomplishments: - Developed the requirements for a low cost, pervasive detection network for wide-area monitoring of radionuclide exposure. - Demonstrated novel manufacturing approaches that can lower the cost of radiation detectors without compromising performance.				
FY 2016 Plans: - Develop high performance radiation detectors for wide-area monitoring and implement novel manufacturing approaches for low cost production. - Develop and study concepts-of-operations for wide-area radiation monitoring networks.				
FY 2017 Plans: - Optimize system models and detection algorithms utilizing multiple sensor inputs for wide-area monitoring of radiation. - Integrate detection algorithms with high performance radiation detectors to form a sensor network for wide-area monitoring. - Demonstrate a wide-area, radiation monitoring, sensor network at large scale through simulation and representative pilot data collections.				
Accomplishments/Planned Programs Subtotals		42.447	24.265	21.250
D. Other Program Funding Summary (\$ in Millions) N/A				
Remarks				
E. Acquisition Strategy N/A				
F. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.				

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>	R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>

COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	299.787	302.582	313.843	-	313.843	381.964	370.283	403.688	407.797	-	-
TT-03: <i>NAVAL WARFARE TECHNOLOGY</i>	-	61.648	52.128	43.024	-	43.024	53.544	64.765	43.451	53.451	-	-
TT-04: <i>ADVANCED LAND SYSTEMS TECHNOLOGY</i>	-	57.521	63.118	52.847	-	52.847	62.527	68.518	96.298	101.298	-	-
TT-06: <i>ADVANCED TACTICAL TECHNOLOGY</i>	-	14.861	13.468	6.500	-	6.500	0.000	0.000	0.000	0.000	-	-
TT-07: <i>AERONAUTICS TECHNOLOGY</i>	-	50.245	31.621	62.876	-	62.876	95.361	62.424	51.434	42.434	-	-
TT-13: <i>NETWORK CENTRIC ENABLING TECHNOLOGY</i>	-	115.512	142.247	148.596	-	148.596	170.532	174.576	212.505	210.614	-	-

A. Mission Description and Budget Item Justification

This program element is budgeted in the Applied Research Budget Activity because it supports the advancement of concepts and technologies to enhance the next generation of tactical systems. The Tactical Technology program element funds a number of projects in the areas of Naval Warfare, Advanced Land Systems, Advanced Tactical Technology, Aeronautics Technology and Network Centric Enabling Technology.

The Naval Warfare Technology project develops advanced technologies for application to a broad range of naval requirements. Enabling and novel technologies include concepts for expanding the envelope of operational naval capabilities such as improved situational awareness over large maritime environments, ship self-defense techniques, novel underwater propulsion modalities, high speed underwater vessels, improved techniques for underwater object detection and discrimination, long endurance unmanned surface vehicles, and high bandwidth communications.

The Advanced Land Systems Technology project is developing technologies for enhancing U.S. military effectiveness and survivability in operations ranging from traditional threats to military operations against irregular forces that can employ disruptive or catastrophic capabilities, or disrupt stabilization operations. The emphasis is on developing affordable technologies that will enhance the military's effectiveness while decreasing the exposure of U.S. or allied forces to enemy fire. This project will also explore novel design technologies for the manufacture of ground vehicles and new tools for systems assessments of emerging DARPA technologies.

The Advanced Tactical Technology project focuses on broad technology areas including compact, efficient, frequency-agile, diode-pumped, solid-state lasers for infrared countermeasures, laser radar, holographic laser sensors, communications, and high-power laser applications.

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide I BA 2: Applied Research</i>	R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>

Aeronautics Technology efforts will address high payoff opportunities that dramatically reduce costs associated with advanced aeronautical systems and/or provide revolutionary new system capabilities for satisfying current and projected military mission requirements. This includes advanced technology studies of revolutionary propulsion and vehicle concepts, sophisticated fabrication methods, and examination of novel materials for aeronautic system applications.

The Network Centric Enabling Technology project develops network-centric mission applications that integrate information arising from: 1) intelligence networks; 2) open and other external sources; 3) sensors and signal/image processors; and 4) collection platforms and weapon systems. Technical challenges include the need to process huge volumes of diverse, incomplete, and uncertain data streams in tactically-relevant timeframes. The data processing efforts include: conditioning of unstructured data, content analysis, behavioral modeling, pattern-of-life characterization, economic activity analysis, social network analysis, anomaly detection, and visualization. Operational benefits include deeper understanding of the evolving operational environment tailored to the needs of commanders at every echelon. Promising technologies are evaluated in the laboratory and demonstrated in the field to facilitate transition.

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	299.734	314.582	386.540	-	386.540
Current President's Budget	299.787	302.582	313.843	-	313.843
Total Adjustments	0.053	-12.000	-72.697	-	-72.697
• Congressional General Reductions	0.000	0.000			
• Congressional Directed Reductions	0.000	-12.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	9.182	0.000			
• SBIR/STTR Transfer	-9.129	0.000			
• TotalOtherAdjustments	-	-	-72.697	-	-72.697

Congressional Add Details (\$ in Millions, and Includes General Reductions)

Project: TT-03: *NAVAL WARFARE TECHNOLOGY*

Congressional Add: *Arctic Operations Congressional Add*

Congressional Add Subtotals for Project: TT-03

Congressional Add Totals for all Projects

FY 2015	FY 2016
4.250	-
4.250	-
4.250	-

Change Summary Explanation

FY 2015: Increase reflects reprogrammings offset by the SBIR/STTR transfer.

FY 2016: Decrease reflects congressional reduction.

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>	R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>	
FY 2017: Decrease reflects completion of the Ground Experimental Vehicle program, the transition of the Endurance program to Budget Activity 3, and drawdown of the XDATA and Network Defense programs.		

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY				Project (Number/Name) TT-03 / NAVAL WARFARE TECHNOLOGY			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
TT-03: NAVAL WARFARE TECHNOLOGY	-	61.648	52.128	43.024	-	43.024	53.544	64.765	43.451	53.451	-	-

A. Mission Description and Budget Item Justification

The Naval Warfare Technology project develops advanced technologies for application to a broad range of naval requirements. Enabling and novel technologies include concepts for expanding the envelope of operational naval capabilities such as improved situational awareness over large maritime environments, ship self-defense techniques, novel underwater propulsion modalities, vessels for estuary and riverine operations, high speed underwater vessels, improved techniques for underwater object detection and discrimination, long endurance unmanned surface vehicles, and high bandwidth communications.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessel (ACTUV)	27.100	6.000	4.000
Description: The Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessel (ACTUV) program has three primary goals: (1) to build and demonstrate an experimental unmanned vessel with beyond state-of-the-art platform performance based on clean sheet design for unmanned operation; (2) demonstrate the technical viability of operating autonomous unmanned craft at theater or global ranges, from forward operating bases, under a sparse remote supervisory control model; and (3) leverage unique ACTUV characteristics to transition a game changing ASW capability to the Navy. By establishing the premise that a human is never intended to step on board at any point in the operational cycle, ACTUV concepts can take advantage of an unexplored design space that eliminates or modifies conventional manned ship design constraints in order to achieve disproportionate speed, endurance, and payload fraction. The resulting unmanned naval vessels must possess sufficient situational awareness and autonomous behavior capability to operate in full compliance with the rules of the road and maritime law to support safe navigation for operational deployments spanning thousands of miles and months of time. When coupled with innovative sensor technologies, the ACTUV system provides a low cost unmanned system with a fundamentally different operational risk calculus that enables game changing capability to detect and track even the quietest diesel electric submarine threats. Key technical areas include unmanned naval vessel design methodologies, ship system reliability, high fidelity sensor fusion to provide an accurate world model for autonomous operation, novel application of sensors for ASW tracking, and holistic system integration due to unique optimization opportunities of the ACTUV system.			
FY 2015 Accomplishments: - Integrated software and hardware into the ACTUV platform. - Initiated development of alternative payloads.			
FY 2016 Plans: - Complete construction of prototype vessel. - Initiate at-sea testing to validate baseline performance of vessel, sensor systems, and autonomy.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY	Project (Number/Name) TT-03 / NAVAL WARFARE TECHNOLOGY	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Move the vessel from the contractor facility to a Navy facility in San Diego for long term testing - with the Office of Naval Research (ONR). - Demonstrate improved situational awareness and autonomy capabilities, incorporating advanced above water sensors. - Demonstrate the ability to successfully integrate new mission payloads, including a Mine Counter Measures (MCM) payload. FY 2017 Plans: - Continue vessel at-sea testing, including tactical exercises with fleet units. - Continue testing of new payloads for MCM, ASW, and other missions. - Transition custody of prototype vessel to the Navy (ONR).			
Title: Upward Falling Payloads (UFP) Description: The Upward Falling Payloads (UFP) program will develop forward-deployed unmanned distributed systems that can provide non-lethal effects or situational awareness over large maritime environments. Building upon and complimenting concepts for maritime situational awareness and ISR developed under the DASH program, budgeted in PE 0603766E, Project NET-02, the UFP approach centers on pre-deploying deep-ocean nodes years in advance in forward operating areas which can be commanded from standoff to launch to the surface. Advances in miniaturized sensors and processors, growth in the variety of unmanned systems, and advances in autonomy and networking all point toward highly capable, yet affordable, distributed systems. However, power and logistics to deliver these systems in a timely manner in forward operating areas limit their utility. The UFP program will remove this barrier to accelerate large-scale unmanned distributed missions. The presumption is that a wider range of technology options and system solutions will emerge when the barriers to deployment are removed. FY 2015 Accomplishments: - Developed UFP nodes scalable in size, to enable extended survival at full depth. - Demonstrated launch of a UFP surrogate payload from land and method for aerodynamically stable deployment of an unmanned aerial vehicle (UAV) from a UFP node. - Initiated design of payload subsystems for sensing, communicating, and locating. - Developed signaling scheme and performed sea test for long range underwater acoustic communications for triggering. - Demonstrated integration of triggered release from surrogate underwater cabled system. - Studied alternative communication modalities. - Demonstrated surfacing of UFP balloon-node riser and deployment of small UAV. FY 2016 Plans: - Demonstrate deep-ocean surfacing of scalable riser prototype to the surface and launch of payload surrogate from UFP node at surface.		18.955	15.901
			14.000

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY	Project (Number/Name) TT-03 / NAVAL WARFARE TECHNOLOGY		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Demonstrate launch of a UFP surrogate payload after being submerged for several months. - Demonstrate long-range acoustic communications sufficient to wake up a UFP node. - Demonstrate launch of UAV from UFP node at surface. FY 2017 Plans: - Develop communications and ISR payloads for UFP nodes. - Demonstrate complete launch of UAV from ocean depth. - Integrate parafoil kite with submerged tow body. - Integrate and demonstrate remote triggering of dormant UFP node. - Conduct major integrated sea test at full depth.				
Title: Strategic Mobility Description: The goal of the Strategic Mobility program is to analyze and perform risk reduction on technology solutions which can enable rapid deployment of brigade- or even division- sized forces globally in a matter of just days. Initially, the activity will focus on identifying high payoff logistics and deployment technologies, and understanding the deployment and sustainment architectures required to support these technologies. The program will examine increased automation in logistics and distribution operations, new platform technologies for sea-based transportation and prepositioning, and technologies which could enable aerial delivery of forces to the vicinity of an objective area. The Strategic Mobility program will then shift to a focused technology risk reduction activity designed to systematically address the principal risks for the highest payoff technology set. The technologies developed by the program could enable a rapid strategic response capability, with rapid deployment and sustainment of substantial ground combat forces, even to very remote or austere locations. FY 2016 Plans: - Create time and cost model of brigade level deployment technologies and processes. - Perform refined technology trade studies to identify critical component technology to aid in extremely rapid loading, unloading, and unpacking of transports and filling of requisitions to include building boxes/pallets and loading of materials into containers. - Initiate studies into foundation and structure required to enable reliable operation of robotic logistics systems in expeditionary environments. FY 2017 Plans: - Complete technology trade studies to identify critical component technologies to aid in extremely rapid loading and unloading of transports, unpacking of supplies from transports, and filling requisitions. - Complete studies in foundation and structure required to enable reliable operation of robotic logistics systems in expeditionary environments.		-	2.727	2.000
Title: Multi-Azimuth Defense Fast Intercept Round Engagement System (MAD-FIRES)		11.343	27.500	23.024

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY	Project (Number/Name) TT-03 / NAVAL WARFARE TECHNOLOGY		
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
Description: The Multi-Azimuth Defense Fast Intercept Round Engagement (MAD-FIRES) program seeks to develop a point defense system against today's most stressing threats by developing a highly maneuverable, medium caliber, guided projectile, fire sequencing and control system capable of neutralizing large threat raids of high speed, highly maneuverable targets. Leveraging recent advancements in gun hardening, miniaturization of guided munition components, and long range sensors, MAD-FIRES will advance fire control technologies, medium caliber gun technologies, and guided projectile technologies enabling the multiple, simultaneous target kinetic engagement mission at greatly reduced costs. MAD-FIRES seeks to achieve lethality overmatch through accuracy rather than size, thus expanding the role of smaller combat platforms into missions where they have been traditionally outgunned. MAD-FIRES, sized as a medium caliber system, enhances flexibility for installment as a new system and as an upgrade to existing gun systems with applications to various domain platforms across a multitude of missions to include: ship self-defense, precision air to ground combat, precision ground to ground combat, counter unmanned air vehicles (C-UAV), and counter rocket and artillery and mortar (C-RAM). FY 2015 Accomplishments: - Initiated technology development efforts focusing on guidance, packaging and delivery method. - Began detailed subsystem design and plans for later stage risk reduction tests and prototyping. - Began end-to-end modeling and simulation of all candidate designs to determine Point of Departure (POD) designs. - Began examining candidate platforms for out-year live-fire tests. - Completed government in-house feasibility and trade study. - Conducted projectile wind tunnel testing to verify performance predictions. FY 2016 Plans: - Determine Point of Departure (POD) designs. - Complete end-to-end modeling and simulation of POD designs. - Begin risk reduction tests and prototyping. - Update models and simulations as designs are modified. - Conduct risk reduction subsystem tests to verify gun hardening and performance. - Perform unguided projectile flight tests to validate aerodynamic models and gun-launch survivability. - Coordinate with Navy for integrated tests to include approved representative targets. FY 2017 Plans: - Update models and simulations of select designs. - Complete preliminary prototype design. - Perform initial controlled projectile flight tests to assess projectile performance. - Conduct fire control tests for target acquisition and tracking and interceptor projectile tracking.					
Accomplishments/Planned Programs Subtotals			57.398	52.128	43.024

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY	Project (Number/Name) TT-03 / NAVAL WARFARE TECHNOLOGY

	FY 2015	FY 2016
Congressional Add: Arctic Operations Congressional Add	4.250	-
FY 2015 Accomplishments: - Conduct additional study work on technologies to assure U.S. capability to achieve situational awareness in the Arctic.		
Congressional Adds Subtotals	4.250	-

C. Other Program Funding Summary (\$ in Millions)

Line Item	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
• ACTUV: Office of Naval Research MOA	2.000	7.000	9.000	-	9.000	4.000	0.000	0.000	0.000	-	-

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency									Date: February 2016			
Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY				Project (Number/Name) TT-04 / ADVANCED LAND SYSTEMS TECHNOLOGY			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
TT-04: ADVANCED LAND SYSTEMS TECHNOLOGY	-	57.521	63.118	52.847	-	52.847	62.527	68.518	96.298	101.298	-	-
A. Mission Description and Budget Item Justification												
This project is developing technologies for enhancing U.S. military effectiveness and survivability in operations ranging from traditional threats to military operations against irregular forces that can employ disruptive or catastrophic capabilities, or disrupt stabilization operations. The emphasis is on developing affordable technologies that will enhance the military's effectiveness while decreasing the exposure of U.S. or allied forces to enemy fire. This project will also explore novel design technologies for the manufacture of ground vehicles and new tools for systems assessments of emerging DARPA technologies.												
B. Accomplishments/Planned Programs (\$ in Millions)									FY 2015	FY 2016	FY 2017	
Title: Ground Experimental Vehicle (GXV)									22.601	24.000	-	
Description: The goal of the Ground Experimental Vehicle (GXV) program is to investigate ground vehicle technologies that enable crew/vehicle survivability through means other than traditional heavy passive armor solutions. This will be accomplished through research and development of novel ground combat and tactical vehicle technology solutions that demonstrate significantly advanced platform mobility, agility, and survivability. The focus of the GXV program will be on technology development across multiple areas to simultaneously improve military ground vehicle survivability and mobility. Traditionally, survivability and mobility have to be traded against each other due to the reliance on heavy armor. The GXV program seeks to break this trend. Coupled with the development of technologies, the GXV program will define concept vehicles which showcase these developmental technologies. A modeling and simulation effort will also be undertaken to understand the vehicle design trade space for the concept vehicles using the developmental technologies and to illustrate how these vehicles might be used operationally in combat scenarios. Technology development areas are likely to include increasing vehicle tactical mobility, survivability through agility, and crew augmentation, though other relevant technologies may also be pursued.												
FY 2015 Accomplishments:												
- Initiated GXV technology development efforts.												
- Began developing parametric models for evaluating military utility of technologies.												
FY 2016 Plans:												
- Continue GXV technology development efforts focused on increasing mobility, survivability through agility and crew augmentation.												
- Mature parametric models for evaluating military utility of technologies.												
- Complete studies focusing on system trades relating to system power requirements, size/caliber of weapon systems, and crew size.												

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>		Project (Number/Name) TT-04 / <i>ADVANCED LAND SYSTEMS TECHNOLOGY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
- Complete studies focusing on the impact of crew augmentation capabilities on the size and cognitive workload of combat vehicle crews. - Conduct survivability analysis of individual concepts.					
Title: Squad X Description: The U.S. military achieves overmatch against its adversaries in certain regimes; however, this level of overmatch is not enjoyed at the squad to individual dismounted warfighter level. The goal of the Squad X program is to leverage advances in real-time situational awareness and mission command; organic three-dimensional dismount mobility; extended range tracking, targeting, and response; and unmanned mobility and perception in order to create a squad with substantial combat overmatch. The concept of overmatch at the squad level includes increased human stand-off, a smaller force density, and adaptive sensing to allow for responses at multiple scales. Squad X will explore advanced wearable force protection, advanced organic squad level direct and indirect trajectory precision weaponry, and non-kinetic precision capabilities. The end result of the Squad X program is an individual dismount unit outfitted with sensors, weaponry, and supporting technology to achieve unit level overmatch as well as the overall integration of unmanned assets alongside the dismounts to create a new Hybrid Squad unit. FY 2015 Accomplishments: - Initiated technology development efforts, focusing on squad precision effects, non-kinetic engagement, enhanced sensor fusion and exploitation, and squad collaborative autonomy. - Completed initial integration and architecture trade studies. - Initiated squad architecture, technology evaluation, and experimentation studies. - Initiated development of virtual, constructive, and live experimentation plan; defined modeling and simulation strategy. - Initiated development of virtual test bed. - Conducted Tactical Edge Standards Boards (TESBs) and service-level operational workshops. FY 2016 Plans: - Complete systems architecture, technology evaluation, and experimentation trade studies. - Conduct Squad X Baseline experimentation, through virtual and live experiments to obtain a system performance baseline. - Refine technology development efforts focusing on squad precision effects, non-kinetic engagement, enhanced sensor fusion and exploitation, and squad collaborative autonomy. - Implement modeling and simulation environment to allow for an overarching iterative design process and obtain system performance estimation. - Leverage Squad X testbed and simulation environments to iteratively assess developed technology and architecture schemes. - Demonstrate initial individual technology capabilities in technology assessments.			25.500	31.118	36.847

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY	Project (Number/Name) TT-04 / ADVANCED LAND SYSTEMS TECHNOLOGY		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Conduct Tactical Edge Standards Boards.				
FY 2017 Plans: - Leverage Squad X testbed and simulation environments to iteratively assess developed technology and architecture schemes. - Leverage virtual testbed to provide predictions of system performance in multiple operational conditions. - Complete Squad X Baseline experimentation. - Initiate planning for system-level experimentation and evaluation in relevant conditions with operational units. - Demonstrate individual technology capabilities for squad precision effects, non-kinetic engagement, enhanced sensor fusion and exploitation, and squad collaborative autonomy in operational environment. - Initiate technology development efforts focusing on human machine interfaces and the squad common operating picture. - Initiate squad-system development efforts focusing on the development of automatic systems to increase squad performance and the integration of previously developed technologies and enhancing for dismounted operations. - Conduct Tactical Edge Standards Boards.				
Title: Counter Unmanned Air Systems (C-UAS) and Force Protection (CFP) Description: The Counter Unmanned Air Systems (C-UAS) and Force Protection (CFP) program will examine advanced detection, tracking, and system defeat capabilities to counter emerging threats posed against U.S. military forces. Key research will include an analysis of system threat phenomenologies where non-state and state actors seek to leverage asymmetries by employing small unmanned systems and other threats to include rocket propelled grenades, anti-tank munitions, and indirect fires. The program will consider technologies supporting U.S. ground, air, and maritime operations. Central research and development will factor in analysis of advanced sensor integration, detection, and weapons engagement capabilities within operationally relevant environments (urban, tactical, and strategic domains). FY 2017 Plans: - Perform trade studies for a systems approach. - Conduct operational analysis and technology maturity assessments to determine the minimum set of critical system attributes and technology advances required for C-UAS and CFP.		-	-	9.000
Title: Mobile Infantry Description: The Mobile Infantry (MI) program will explore the development of a system-based, mixed team of mounted/ dismounted warfighters, and semi-autonomous variants of platforms. The MI system concept will allow for a combined set of mounted and dismounted operations and for a larger area of operations over more aggressive timelines than standard infantry units. To improve operational effectiveness of the warfighter teams when dismounted, the semi-autonomous platforms, when		-	6.000	7.000

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>	Project (Number/Name) TT-04 / <i>ADVANCED LAND SYSTEMS TECHNOLOGY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
unmanned, act as multipliers to the squad, such as extended and mobile fire support platforms and allow the MI mixed teams to perform higher risk exposure and access missions.			
FY 2016 Plans: - Complete trades of mission/vignette-driven collaborative command and control of a MI unit composed of a warfighter team and semi-autonomous systems. - Complete trade studies and initial estimates of perception and autonomous algorithms required to match vignettes. - Complete trade studies of candidate platforms and options for conversion, system integration, interfaces (electrical, mechanical, software, etc.), and define preliminary warfighter architectures to leverage.			
FY 2017 Plans: - Initiate technology development efforts for critical perception and autonomous algorithms to enable semi-autonomous systems to act as force multipliers for warfighter team. - Initiate technology development efforts for critical collaborative behavior algorithms to enable semi-autonomous systems to cooperatively execute missions without human interaction. - Initiate technology development efforts for critical technologies to enable effective command and control of manned and unmanned warfighter team.			
Title: Robotics Fast Track Description: To be dominant in robotics of the future, the DoD will need to embrace programs designed to create disruptive advances in robotics capabilities that are measured in months rather than years, and whose individual costs may largely be measured in thousands of dollars rather than millions. The Robotics Fast Track program seeks to revolutionize robotics technologies by promoting non-traditional technical opportunities. The program will create low-cost, high-utility robotic component solutions that result in prototype systems and proofs of concept in months. The Robotics Fast Track program will engage numerous robotics related efforts across the spectrum of robotics professionals and enthusiasts, extending the existing performer base. The program will demonstrate the ability for robotics projects to be performed at an asymmetric advantage in time, cost, and contribution of the efforts.		4.500	2.000
FY 2015 Accomplishments: - Began execution of multiple performance developments.			
FY 2016 Plans: - Continue execution of multiple performance developments. - Release initial robotics fast track catalog.			-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>	Project (Number/Name) TT-04 / <i>ADVANCED LAND SYSTEMS TECHNOLOGY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Host transition workshops to facilitate follow-on developments with other U.S. government entities.			
Title: Robotics Challenge Description: The Robotics Challenge program sought to boost innovation in autonomous systems and expand platform utility through enhanced actuation, energy density, perception, locomotion, agile reconfiguration, and design efficiency. Program thrusts were centered on a progressive regimen of physical problem solving, real-time team oriented tasks, and dynamic adaptation designed to build "machine trust", especially when integrated with humans in a variety of operational environments. The Robotics Challenge program consisted of a series of obstacle course style challenge events that focused on technology solutions to demonstrate and test robot capabilities for disaster response. The program drove advances in power systems, agility and speed, precision in perception tied to platform coordination, dexterity, and impulsive power. Program objectives focused on technologies to expand mobility and extend endurance of unmanned platforms, advanced tactile and manipulation capabilities, and tools for cost effective design, validation, and construction of autonomous technology, and human-robot interaction. The 6.3 portion of this program was budgeted in PE 0603766E, Project NET-01. FY 2015 Accomplishments: - Conducted the DARPA Robotics Challenge Finals. - Performed analysis and reported findings to document advancements achieved as a result of the challenge.		4.920	-
Accomplishments/Planned Programs Subtotals		57.521	63.118
C. Other Program Funding Summary (\$ in Millions) N/A Remarks D. Acquisition Strategy N/A E. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY				Project (Number/Name) TT-06 / ADVANCED TACTICAL TECHNOLOGY			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
TT-06: ADVANCED TACTICAL TECHNOLOGY	-	14.861	13.468	6.500	-	6.500	0.000	0.000	0.000	0.000	-	-
A. Mission Description and Budget Item Justification												
This project focuses on broad technology areas including compact, efficient, frequency-agile, diode-pumped, solid-state lasers for a variety of applications including infrared countermeasures, laser radar, holographic laser sensors, chemical sensing, communications, and high-power laser applications.												
B. Accomplishments/Planned Programs (\$ in Millions)									FY 2015	FY 2016	FY 2017	
Title: Laser Ultraviolet Sources for Tactical Efficient Raman (LUSTER)									4.500	7.000	6.500	
Description: The Laser Ultraviolet Sources for Tactical Efficient Raman (LUSTER) program is developing a compact semiconductor laser that emits in the deep UV (i.e., wavelength < 250 nanometers (nm)) and is capable of an output power of 1 Watt (W) with high efficiency and spectral purity suitable for a wide array of spectroscopy applications. Such an achievement will represent a significant advance over the state of the art, as existing lasers in this wavelength range are bulky, highly inefficient, and expensive, as there are no available semiconductor lasers that can emit in the UV range < 250 nm. LUSTER will leverage lessons learned in growing high quality light emitting material from the Compact Mid-Ultraviolet Technology (CMUVT) program. The compact size of semiconductor lasers along with the LUSTER performance goals will enable many applications including but not limited to standoff Raman spectroscopy which is of interest for DoD applications such as chemical agent sensing.												
FY 2015 Accomplishments:												
- Demonstrated low loss thulium doped tellurite fibers for use in amplification of blue emission.												
- Demonstrated high quality quantum well material that exhibited optically pumped UV emission in the 220-240 nm range.												
- Initiated the design and growth of laser epitaxial material, focusing on low-defect growth, optimal electrical and optical confinement, and methods for high efficiency and power operation.												
- Evaluated methods for using non-linear crystals to efficiently convert longer wavelength lasers in the 500 nm range down to the 250 nm range and identified Beta Barium Borate (BBO) as best performing non-linear optical crystal.												
FY 2016 Plans:												
- Optimize laser epitaxial material, electron-beam source, and frequency multiplying nonlinear crystals for higher efficiency and high power operation.												
- Develop compact low power electronics for driving and controlling photonic and mechanical components.												
- Demonstrate working prototype of a deep UV laser system that meets the Phase 1 metrics of > 100 mW output power, 0.4% total system efficiency and line width less than 0.1 nm.												
FY 2017 Plans:												

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>		Project (Number/Name) TT-06 / <i>ADVANCED TACTICAL TECHNOLOGY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
- Demonstrate a deep UV laser system that meets the Phase 2 metrics of > 1 W output power, 10% total system efficiency, line width less than 0.01 nm and size < 2 in^3.					
Title: Endurance Description: The Endurance program will develop technology for pod- or internally-mounted lasers to protect airborne platforms from emerging and legacy electro-optical/infrared (EO/IR) guided surface-to-air missiles. The Endurance system will be a completely self-contained laser weapon system brassboard in an open architecture configuration. The focus will be on miniaturizing component technologies, developing high-precision target tracking, identification, and lightweight agile beam control to support target engagement. The program will also focus on determining the laser irradiance and dwell time required to defeat both emerging and legacy missile threats. The advanced technology component of this program is budgeted in PE 0603739E, Project MT-15. FY 2015 Accomplishments: - Spectrally combined the output of four kW-class, near perfect beam quality fiber lasers in a packaged compact, rugged spectral beam combiner. - Achieved the objective high-speed slew and settle rates for the beam director (BD) with an inertial surrogate of the preliminary BD design. - Developed a concept for robust high-precision tracking of threat missiles throughout the engagement. - Initiated a live-fire test plan in conjunction with all the stakeholders (Government test team, performer, target logistics, range support, range safety and environmental offices, laser clearing house, etc.). FY 2016 Plans: - Conduct effects testing on an available surrogate of the seeker of a larger class of threat EO/IR guided surface-to-air missile to verify estimated lethality criteria and anchor lethality models. - Complete a live-fire test plan in conjunction with all the stakeholders (Government test team, performer, target logistics, range support, range safety and environmental offices, laser clearing house, etc.). - Conduct key risk reduction experiments to support the design of robust, high-precision tracking. - Demonstrate robust, high-precision tracking against multiple low-speed surrogate targets at representative angular line-of-sight rates and ranges. - Partially-package high-power laser for pod-integration testing. - Fabricate and test smallest high-power beam director and control system yet demonstrated.			7.161	6.468	-
Title: International Space Station SPHERES Integrated Research Experiments (InSPIRE) Description: The International Space Station SPHERES Integrated Research Experiments (InSPIRE) program utilized the DARPA-sponsored Synchronized Position, Hold, Engage, and Reorient Experimental Satellites (SPHERES) platform, which has			3.200	-	-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>	Project (Number/Name) TT-06 / <i>ADVANCED TACTICAL TECHNOLOGY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
flown onboard the International Space Station (ISS) since May 2006, to perform a series of multi-body formation flight experiments that necessitate a medium-duration zero-gravity environment. InSPIRE enhanced the ability to rapidly mature and insert new technologies into national security space assets. The InSPIRE program expanded on the capabilities matured through SPHERES by developing, building, and launching new hardware and software elements that expand the baseline capabilities. These capabilities will enable use of SPHERES as a testbed for more complex experimentation, providing affordable opportunities to test new space technologies. <i>FY 2015 Accomplishments:</i> - Launched the new docking ports for SPHERES to enhance rendezvous and docking test capabilities. - Conducted on-orbit testing of new SPHERES docking ports. - Developed and executed additional rendezvous and proximity operations experiments using SPHERES inside ISS.			
Accomplishments/Planned Programs Subtotals		14.861	13.468
C. Other Program Funding Summary (\$ in Millions)			
N/A			
Remarks			
D. Acquisition Strategy			
N/A			
E. Performance Metrics			
Specific programmatic performance metrics are listed above in the program accomplishments and plans section.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY				Project (Number/Name) TT-07 / AERONAUTICS TECHNOLOGY			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
TT-07: AERONAUTICS TECHNOLOGY	-	50.245	31.621	62.876	-	62.876	95.361	62.424	51.434	42.434	-	-
A. Mission Description and Budget Item Justification												
Aeronautics Technology efforts will address high payoff opportunities that dramatically reduce costs associated with advanced aeronautical systems and/or provide revolutionary new system capabilities for satisfying current and projected military mission requirements. This includes advanced technology studies of revolutionary propulsion and vehicle concepts, sophisticated fabrication methods, and examination of novel materials for aeronautic system applications.												
B. Accomplishments/Planned Programs (\$ in Millions)									FY 2015	FY 2016	FY 2017	
Title: Aircrew Labor In-cockpit Automation System (ALIAS)									20.284	14.621	19.876	
Description: The Aircrew Labor In-cockpit Automation System (ALIAS) program will design, develop, and demonstrate a kit enabling affordable, rapid automation of selected aircrew functions across a broad range of aircraft. ALIAS intends to enable reduction of aircrew workload and/or the number of onboard aircrew to improve performance. The program will develop hardware and software to automate select aircrew functions and will employ novel, low impact approaches to interface with existing aircraft monitoring and control systems. The program will also develop tractable approaches to rapidly capture crew-station specific skills and aircraft unique behaviors. To accomplish this, ALIAS will leverage recent advances in perception, manipulation, machine learning, reusable software architectures, autonomous systems architecture, and verification and validation. ALIAS will culminate in a demonstration of the ability to rapidly adapt a single system to multiple aircraft and execute simple missions. This reliability enhancement capability will enable new operational concepts for reuse of existing air assets and allow a reduction in the number of aircrew required.												
FY 2015 Accomplishments:												
- Designed and commenced prototyping of an initial ground-based ALIAS system.												
- Initiated simulator-based demonstration of complete automation system including training and adaptation of system to multiple crew member roles.												
- Conducted ground and airborne risk reduction testing and demonstrations.												
FY 2016 Plans:												
- Perform ground demonstration of ALIAS system mission functionality.												
- Conduct flight demonstration of contingency management and new command interface.												
- Demonstrate portability to new aircraft type.												
- Continue risk reduction activities.												
FY 2017 Plans:												
- Conduct flight demonstration of perception and actuation subsystems.												

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>		Project (Number/Name) TT-07 / <i>AERONAUTICS TECHNOLOGY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
- Perform ground demonstration of portability timeline into other aircraft. - Initiate airworthiness evaluation for integrated flight demonstration. - Initiate the transition of select knowledge acquisition, perception, and interface technologies to operational aircraft.					
Title: Advanced Aeronautics Technologies Description: The Advanced Aeronautics Technologies program will examine and evaluate aeronautical technologies and concepts through applied research. These may include feasibility studies of novel or emergent materials, devices and tactics for both fixed and rotary wing air vehicle applications, as well as manufacturing and implementation approaches. The areas of interest range from propulsion to control techniques to solutions for aeronautic mission requirements. The result of these studies may lead to the design, development, and improvement of prototypes. FY 2015 Accomplishments: - Initiated new studies of novel technologies. FY 2016 Plans: - Perform modeling of concepts and architectures. - Conduct trade studies of emerging concepts. FY 2017 Plans: - Perform testing of enabling technology components. - Initiate conceptual system designs.			2.000	2.000	2.000
Title: Gremlins Description: The goal of the Gremlins program is to develop platform technologies that enable a new class of distributed warfare. The Gremlins concept envisions small air-launched unmanned systems that can be responsively dispatched in volley quantity from commodity platforms, fly into contested airspace, conduct a moderate duration mission, and ultimately be recovered. Key enabling technologies for the concept include smaller developmental payloads that benefit from multiple collaborating host platforms. The Gremlins program will conduct risk reduction and development of the host platform launch and recovery capability and develop and demonstrate a recoverable UAV platform concept. Enabling platform technologies will include precision relative navigation, advanced computational modeling, variable geometry stores, compact propulsion systems, and high speed digital flight control. The program will leverage these technologies, perform analytic trade studies, conduct incremental development, and ultimately demonstrate the potential for an integrated air-launched Gremlins unmanned platform. FY 2016 Plans: - Conduct exploratory trade studies to establish feasibility of technical approaches. - Initiate studies on integration with existing Service systems and systems architectures.			-	15.000	36.000

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY	Project (Number/Name) TT-07 / AERONAUTICS TECHNOLOGY		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Conduct system concept design tradeoff analyses. FY 2017 Plans: - Initiate engineering of integrated demonstration concepts. - Conduct system and subsystem risk reduction test planning. - Develop objective system concepts and mission capability projections. - Complete Preliminary Design Review for demonstration system.				
Title: Swarm Challenge Description: The goal of the Swarm Challenge is to develop autonomous swarming algorithms for Unmanned Vehicles (UxVs) to augment ground troops performing missions in a complex environment, without creating a significant cognitive burden. The program will evaluate the effectiveness of swarming for UxVs supporting ground operations, air operations, maritime operations, undersea operations, or search and rescue operations. Challenges include the ability for the UxV to collaborate to rapidly survey an area leveraging other UxVs to solve problems related to, for example, perception, decision making, or obstacle clearing. The challenge emphasizes minimum operator training and supervision so that the operator can continue to perform his/her normal duties while using UxVs as force multipliers. FY 2015 Accomplishments: - Performed trade studies for system approach. - Select architecture for software, communication, computation, perception, and simulation environment. - Develop autonomous algorithms and associated software.		3.000	-	-
Title: 21st Century Propellants Description: The 21st Century Propellants program will examine new classes of solid propellants capable of affording solid fueled rockets the ability to perform in a greater range of operating scenarios. The program will provide current and future missile systems the flexibility in speed-range combinations unachievable in current solid propellants and will reduce current volume and weight forms for smaller rocket systems. Successful propellant systems for this program must demonstrate a controlled burn rate, restart capability, termination control, improved safety, and a dramatically improved shelf life (>15 years). The program will also address critical issues of safer manufacturing (improved operational handling, transportability issues, and improved environmental impact). Advanced manufacturing methods are of special interest because they can assure reproducibility and can support building custom propellant grains for different rocket systems. FY 2017 Plans: - Initiate new studies of novel technologies. - Conduct risk reduction tests of candidate technologies.		-	-	5.000
Title: Vertical Take-Off and Landing (VTOL) Technology Demonstrator		21.961	-	-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY	Project (Number/Name) TT-07 / AERONAUTICS TECHNOLOGY	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
Description: The Vertical Take-Off and Landing (VTOL) Technology Demonstrator program will demonstrate revolutionary improvements in (heavier than air) VTOL air vehicle capabilities and efficiencies through the development of subsystem and component technologies, aircraft configurations, and system integration. The program will build and flight test an unmanned 10,000 - 12,000 lb aircraft capable of sustained speeds in excess of 300 kt, demonstrate system level hover efficiency within 25% of the ideal power loading, and a lift-to-equivalent drag ratio no less than ten. Additionally, the demonstrator will be designed to have a useful load of no less than 40% of the gross weight with a payload capacity of at least 12.5% of the gross weight. A strong emphasis will be placed on the development of elegant, multi-functional subsystem technologies that demonstrate net improvements in aircraft efficiencies to enable new and vastly improved operational capabilities. In FY 2016, VTOL Technology Demonstrator will be funded in PE 0603286E, Project AIR-01. FY 2015 Accomplishments: - Initiated preliminary design of configuration and all subsystems. - Held system definition reviews to evaluate subsystem integration into air vehicle design and technology development paths to meet program objectives. - Performed subscale wind tunnel and laboratory testing for aerodynamic data base and flight controls development. - Refined power generation and distribution/integration concepts. - Performed propulsion and power system scaled model bench testing. - Designed and developed subscale flight models for configuration viability and control law validation. - Fabricated and began ground testing of subscale model in preparation for flight testing in FY 2016. - Validated computational performance predictions against empirical data. - Refined full scale engine integration design. - Created detailed system integration plans. - Prepared detailed airworthiness and flight test preparation requirements in support of the subscale flight test schedule.			
Title: Petrel Description: The Petrel program investigated advanced capabilities for the rapid transport of large quantities of cargo and equipment, such as during the deployment of a heavy brigade combat team, from CONUS to the battlefield, reducing the deployment timeline for mechanized land forces and critical supplies anywhere in the world to under seven days at a price point comparable or slightly in excess of conventional sealift. FY 2015 Accomplishments: - Investigated component technologies with potential to enable specific concepts, including advanced propulsion and materials. - Explored innovative approaches for significantly increasing lift to drag ratio.		3.000	-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>	Project (Number/Name) TT-07 / <i>AERONAUTICS TECHNOLOGY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Evaluated approaches to rapidly deliver cargo and equipment directly from offshore to the battlefield without infrastructure.			
Accomplishments/Planned Programs Subtotals		50.245	31.621
C. Other Program Funding Summary (\$ in Millions)			
N/A			
Remarks			
D. Acquisition Strategy			
N/A			
E. Performance Metrics			
Specific programmatic performance metrics are listed above in the program accomplishments and plans section.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY				Project (Number/Name) TT-13 / NETWORK CENTRIC ENABLING TECHNOLOGY			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
TT-13: NETWORK CENTRIC ENABLING TECHNOLOGY	-	115.512	142.247	148.596	-	148.596	170.532	174.576	212.505	210.614	-	-
A. Mission Description and Budget Item Justification												
The Network Centric Enabling Technology project develops applications that integrate information arising from: 1) intelligence networks; 2) open and other external sources; 3) sensors and signal/image processors; and 4) collection platforms and weapon systems. Technical challenges include the need to process huge volumes of diverse, incomplete, and uncertain data in tactically-relevant timeframes. The data processing efforts include: conditioning of unstructured data, content analysis, behavioral modeling, pattern-of-life characterization, economic activity analysis, social network analysis, anomaly detection, and visualization. Operational benefits include deeper understanding of the evolving operational environment tailored to the needs of commanders at every echelon. Promising technologies are evaluated in the laboratory and demonstrated in the field to facilitate transition.												
B. Accomplishments/Planned Programs (\$ in Millions)									FY 2015	FY 2016	FY 2017	
Title: XDATA									31.217	32.917	13.896	
Description: The XDATA program is developing computational techniques and software tools for analyzing large volumes of data, both semi-structured (e.g., tabular, relational, categorical, metadata, spreadsheets) and unstructured (e.g., text documents, message traffic). Central challenges addressed include a) development of scalable algorithms for processing imperfect data in distributed data stores, and b) creation of effective human-computer interaction tools for facilitating rapidly customizable visual reasoning for diverse missions. The program has developed open source software toolkits that enable flexible software development supporting users processing large volumes of data in timelines commensurate with mission workflows of targeted defense applications. An XDATA framework supports minimization of design-to-deployment time of new analytic and visualization technologies on diverse distributed computing platforms, and also accommodates changing problem spaces and collaborative environments.												
FY 2015 Accomplishments:												
- Developed methods for interactive, iterative, and distributed analysis of diverse data at petabyte scale.												
- Optimized analytic methods and software for implementation on heterogeneous platforms and operating environments.												
- Optimized visualization technology to rapidly adapt to new missions and contexts.												
- Demonstrated the initial implementation of a rich library of software tools for rapid use in mission and user specific contexts.												
- Demonstrated end-to-end systems on data and problems of users from DoD, intelligence, and law enforcement communities.												
FY 2016 Plans:												
- Develop methods and software for interactive, iterative, distributed analysis of diverse data enabling transition, integration and implementation on heterogeneous platforms.												

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>		Project (Number/Name) TT-13 / <i>NETWORK CENTRIC ENABLING TECHNOLOGY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
- Develop new analytic methods for distributed data and systems through the development of enhanced machine learning and algorithmically scalable methods. - Develop a scalable, robust framework for user-defined, adaptable visualizations. - Develop, test and benchmark a library of user interfaces which provide a consistent user experience independent of scale or processor heterogeneity. - Demonstrate that applications deployed from a library of interfaces reduce design to testing time and increase reusability of components across multiple mission systems and user-defined requirements. FY 2017 Plans: - Develop integrated applications from components and interface libraries demonstrating flexible adaptation to emergent user requirements and ad-hoc tasking. - Optimize software components and integrated applications to allow seamless integration into a user enterprise or mission environment. - Transition end-to-end systems, components, platforms and operating environments to identified user communities.					
Title: Network Defense Description: The Network Defense program is developing technologies to detect network attacks using network summary data. U.S. computer networks are continually under attack, and these attacks are typically handled by individual organizations as they occur. Analyzing network summary data across a wide array of networks will make it possible to identify trends and patterns visible only when the data is viewed as a whole and to detect recurring threats, patterns of activity, and persistent vulnerabilities. Network Defense is developing novel algorithms and analysis tools that enable a big picture approach for identifying illicit behavior in networks. This analysis and subsequent feedback to system administrators, security engineers, and decision makers will enhance information security in both the government and commercial sectors. FY 2015 Accomplishments: - Enhanced network analytics to detect structured attacks across multiple networks. - Created general purpose algorithms for detecting novel classes of attacks across multiple networks. - Developed methods for identifying persistent vulnerabilities within a network and across multiple networks. - Evaluated and optimized techniques on realistic network data. FY 2016 Plans: - Develop algorithms that use scanning events to provide indications and warning of coordinated adversary activities. - Enhance persistent vulnerability detection techniques and work with potential users to identify vulnerabilities particular to individual organizations/networks and/or shared by multiple organizations/networks.			27.500	31.002	16.500

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>	Project (Number/Name) TT-13 / <i>NETWORK CENTRIC ENABLING TECHNOLOGY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Demonstrate the capability to use summary information about an attack on one network to automatically detect similar attacks on other networks. FY 2017 Plans: - Optimize algorithms that detect anomalous behaviors and coordinated adversary activities through exercises using summary data and on-site evaluations. - Demonstrate the capability to anticipate specific attack formats on one network based on attacks observed on other similar networks. - Perform comprehensive test and evaluation of the multiple detection algorithms developed to produce quantitative understanding of probabilities of detection and false alarm and receiver operating characteristic curves for important classes of attacks. - Transition capabilities to U.S. government, defense industrial base organizations/networks, and other U.S. commercial companies.			
Title: Memex Description: The Memex program is developing the next generation of search technologies to revolutionize the discovery, organization, and presentation of domain-specific content. Current search technologies have limitations in search query format, retrieved content organization, and infrastructure support and the iterative search process they enable is time-consuming and inefficient, typically finding only a fraction of the available information. Memex is creating a new domain-specific search paradigm to discover relevant content and organize it in ways that are more immediately useful to specific missions and tasks. In addition, Memex domain-specific search engines will extend the reach of current search capabilities to the deep web and non-traditional content. Memex technologies will enable the military, government, and commercial enterprises to find and organize mission-critical information on the Internet and in large intelligence repositories. Anticipated mission areas include counter-terrorism, counter-drug, anti-money-laundering, and anti-human-trafficking, with transition partners from DoD and other U.S. government activities. FY 2015 Accomplishments: - Developed initial domain-specific search engines to automatically discover, access, retrieve/extract, parse, process, analyze, and manage web content in specified domains. - Implemented the base capabilities to index the surface, deep, and dark web and non-traditional structured and unstructured content that is dynamically-generated, unlinked, and in unconventional formats. - Developed information extraction techniques to categorize and classify discovered content based on mission/user task requirements. - Developed dynamic, interactive, and collaborative user interface capabilities to support the needs of specialized users.		22.338	29.300
			27.700

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY	Project (Number/Name) TT-13 / NETWORK CENTRIC ENABLING TECHNOLOGY		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Developed search techniques optimized for queries performed for anti-human-trafficking investigations and provided these to law enforcement to support case development and criminal prosecution. FY 2016 Plans: - Develop specialized search techniques for information discovery in networks of illicit activity. - Develop advanced content discovery, deep crawling, information extraction, and information relevance algorithms to support domain specific search. - Integrate and evaluate multiple end-to-end operational prototypes with automated, user, and team guided methods for web content analysis. - Conduct system evaluation with feedback from operational partners and transition mature capabilities for use in operational settings. FY 2017 Plans: - Develop advanced domain search techniques and methods across the data pipeline (domain specification, crawlers, extractors, indexing, search, analytics, and visualization) that are domain agnostic, highly adaptable, and rapidly deployed. - Develop integrated applications from Memex components demonstrating reduced time and increased flexibility of standing up new domain specific search capabilities with highly effective user experience. - Transition software components and integrated systems, and demonstrate enhanced support for partner missions. - Establish and develop software and user communities around open source components and applications to ensure tool sustainment, software evolution, and long-term operational use.				
Title: Distributed Battle Management (DBM) Description: The Distributed Battle Management (DBM) program will develop mission-driven architectures, protocols, and algorithms for battle management (BM) in contested environments. The military is turning to networked weapons and sensors on-board a heterogeneous mix of multi-purpose manned and unmanned systems. In contested environments, it is a challenge for BM networks to communicate with subordinate platforms due to extensive adversarial cyber and electronic warfare operations, anti-satellite attacks, and the need for emissions control in the face of a formidable integrated air defense system. The Distributed Battle Management program will seek to develop a distributed command architecture with decentralized control of mission-focused asset teams. The architecture will enable rapid reaction to ephemeral engagement opportunities and maintain a reliable BM structure, despite limited communications and platform attrition in continuously evolving threat environments. The program will incorporate highly automated decision making capability while maintaining vital human-on-the-loop operator approval. FY 2015 Accomplishments: - Developed detailed system architecture for the distributed battle management system.		11.024	14.440	18.000

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY	Project (Number/Name) TT-13 / NETWORK CENTRIC ENABLING TECHNOLOGY		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Developed workflow and Concepts of Operations (CONOPS) for the human operator to interact with the battle management system. - Developed and prototyped the protocols and algorithms for distributed battle management in a denied environment. - Stood-up modeling and simulation capability for test and performance evaluation and began testing of prototype architecture and algorithms. FY 2016 Plans: - Identify and further research the most promising planning concepts, situation understanding concepts, and systems integrator. - Complete design of the overall DBM system, to include architecture, software components, CONOPS, and integration strategy for expected host platforms. - Implement initial version of the integrated DBM system architecture, algorithms, and software. - Demonstrate initial version's capabilities in a simulated battle environment with impaired communications and loss of critical resources. FY 2017 Plans: - Update DBM algorithms and architecture based on experimentation to support complex contested environments. - Continue development of the DBM human-machine interface for battle management platforms and tactical platforms. - Demonstrate integrated DBM capabilities in live, virtual, and constructive simulations. - Conduct software flexibility tests to demonstrate the ability to insert software upgrades without disrupting the BM structure.				
Title: Quantitative Crisis Response (QCR)* Description: *Previously Quantitative Methods for Rapid Response (QMRR) The Quantitative Crisis Response (QCR) program develops and applies big data analysis and visualization methodologies to better understand the true nature of non-traditional threats, track the effectiveness of remedial measures, and develop/optimize alternative strategies. Recently we have seen the rise of extremely challenging non-traditional threats including illicit networks of (human) traffickers and infectious diseases like Ebola. To counter illicit networks it is important to detect their activities, which often take place on the dark web, and derive their command and control structure. Infectious disease contagion presents a somewhat different challenge, specifically, finding patterns in the spread of the disease and factors that favor/mitigate its propagation. There is also interest in quantitative methods for countering the proliferation of weapons of mass terrorism. QCR will be coordinated with and transitioned to multiple national security agencies. FY 2015 Accomplishments: - Developed quantitative models to track the impact of Ebola on a population, with emphasis on social and economic factors.		7.600	15.588	21.500

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>	Project (Number/Name) TT-13 / <i>NETWORK CENTRIC ENABLING TECHNOLOGY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Developed advanced content discovery, deep crawling, information extraction, and information relevance algorithms to support search, analysis and visualization of collected information. - Coordinated with stakeholders in national security agencies and developed mechanisms for transitioning technology to operations. FY 2016 Plans: - Refine quantitative models, content discovery, deep crawling, information extraction, and information relevance algorithms to support search, analysis and visualization of collected information. - Generalize mechanisms and harden collection and processing architectures to respond to rapid re-direction of system resources and apply developed models, processes and methods to other areas of national security interest. - Develop dynamic, interactive, and collaborative user interface capabilities to support the needs of users. - Develop quantitative models to discover indicators of possible proliferation of weapons of mass terrorism. FY 2017 Plans: - Integrate collection architectures, analytic models, processes and methods into operational prototypes. - Evaluate multiple end-to-end operational prototypes with automated, user, and team guided methods for web content analysis and visualization. - Conduct system evaluation with feedback from operational partners and transition mature capabilities for use in operational settings. - Develop algorithms for extracting trace signals from large data sets to enable tracking potential proliferation of weapons of mass terrorism.			
Title: Media Forensics (MediFor) Description: The Media Forensics (MediFor) program will create technologies for analyzing diverse types of content and media to determine their trustworthiness for military and intelligence purposes. Current approaches to media forensics are manpower intensive and require analysts and investigators to undertake painstaking analyses to establish context and provenance. MediFor will develop, integrate, and extend image and video analytics to provide forensic information that can be used by analysts and automated systems to quickly determine the trustworthiness of open source and captured images and video. Technologies will transition to operational commands and the intelligence community. This program was previously funded in PE 0603767E, Project SEN-03. FY 2015 Accomplishments: - Formulated approaches for automatically detecting when image and video files have been altered or manipulated. - Collected images and videos and manually manipulated a subset for training and evaluation of the technology.		9.729	14.000
			18.000

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY	Project (Number/Name) TT-13 / NETWORK CENTRIC ENABLING TECHNOLOGY		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Initiated development of techniques for detecting inconsistent observations. FY 2016 Plans: - Develop advanced techniques for media fingerprinting and the ability to search large repositories for content produced by the same device. - Define processes and practices for the scientific grounding of integrity of visual media, including detection of pixel level manipulations and inconsistencies in shadows/illumination and motion/trajectories. - Develop cross media representations of semantic content in image and video sources and techniques to indicate where the sources reinforce or contradict each other. - Collect and manipulate additional images and videos for evaluation and training of algorithms. FY 2017 Plans: - Develop approaches for countering evolving media editing technologies. - Develop approaches to detect manipulation in noisy, degraded and highly compressed media. - Develop means to fuse knowledge from the various technology components and inference engines to determine the relation between manipulation and the intended application. - Develop an integrated platform with Graphical User Interfaces (GUIs) for operator communication.				
Title: Science of Human and Computer Teaming Description: The Science of Human and Computer Teaming program will develop and demonstrate data-driven approaches for the formation and training of teams comprised of humans and computers. Conventional approaches to military personnel selection, role assignment, and training are optimized for individual performance, but military operations are typically performed by teams, and future teams are likely to also include autonomous systems that use artificial intelligence (AI) to sense, reason, learn, and interact. Behavioral scientists are studying the performance of groups across diverse sets of tasks and developing performance assessment techniques for group work. Interesting early results suggest that groups exhibit a form of intelligence beyond that of the individual members, and that group intelligence has social correlates. Computer scientists are looking at ways in which humans may team with computers to achieve superior levels of performance. Such human-computer teams have shown great promise in highly structured competitive domains such as chess. Realizing this promise in free-form (battlefield) environments will require intuitive, low-latency, high-bandwidth, human-computer interfaces that enable computers to be better teammates. The program will identify individual characteristics predictive of performance of mixed human-computer teams; develop techniques for measuring these characteristics in military personnel; demonstrate the capability to select, assign roles, and train human-computer teams with performance superior to that of human-only teams formed and trained using current methods; and develop an understanding of how to structure human-computer teams for superior performance on military missions such as cyber defense and intelligence analysis.		-	-	15.000

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY	Project (Number/Name) TT-13 / NETWORK CENTRIC ENABLING TECHNOLOGY	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
FY 2017 Plans: - Develop group psychometrics concepts applicable to human-computer teams. - Identify individual characteristics that are readily measured and are predictive of individual performance in human-computer teams assigned specific military task types. - Develop quantitative approaches for creating high-performing human-computer teams through the inclusion of individuals and computers/autonomous systems with complementary characteristics. - Develop human-computer-interface design principles that optimize the contribution made by computer-based teammates to human-computer team performance. - Formulate human-machine teaming strategies for military missions such as cyber defense and intelligence analysis.			
Title: Predicting Complex Operational Environments Description: The Predicting Complex Operational Environments program expands on prior work in the XDATA program and will develop advanced modeling, analysis, simulation, and visualization tools to enable command staffs to rapidly and effectively plan and manage missions in complex operational environments. The U.S. military increasingly operates in remote and unstable parts of the world where mission success depends heavily on cooperation with and among a wide variety of stakeholder groups. These groups typically include host nation government organizations, local civilian groups, and non-governmental organizations each of which has priorities, sensitivities and concerns that may differ significantly. Economic disruptions can add great urgency to these considerations, as shortages of water and food directly impact theater security and may even lead to war. Current mission planning and plan assessment/adaptation technologies do not adequately model the inherent uncertainties. Addressing this challenge will require the creation of new semantic techniques that automatically generate, update, and prune alternative hypotheses as they become more or less likely given incoming data streams. The program will create computational models that represent the most significant dynamics and uncertainties of the operational environment including political, military, economic, and social factors. These will enable command staffs to develop and assess potential courses of action at multiple levels of granularity and time scales, and to quickly adapt to changing situations in complex operational environments.		-	5.000
FY 2016 Plans: - Formulate computational models for political, military, economic, and social factors in complex operational environments to support military planning and plan assessment/adaptation at multiple levels of granularity and time scales. - Create semantic techniques that automatically generate, update, and prune alternative hypotheses as they become more or less likely given incoming data streams.			
FY 2017 Plans: - Develop dynamical systems models for projecting and predicting the interactions between diverse stakeholder groups that may have differing priorities, sensitivities and concerns.			18.000

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / TACTICAL TECHNOLOGY	Project (Number/Name) TT-13 / NETWORK CENTRIC ENABLING TECHNOLOGY	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Develop displays for rapidly visualizing and evaluating likely outcomes of alternative U.S. courses of action. - Implement models for operational environments and run initial simulations that would be required to support military planning and plan assessment/adaptation. - Introduce models that capture the impact of natural and human-mediated perturbations, such as water shortages, crop failures, and hoarding of critical resources, on theater security. - Develop machine-reading and automated model assembly techniques to enable prediction of the theater security ramifications of natural resource shortages and economic disruptions.			
Title: Visual Media Reasoning (VMR) Description: The Visual Media Reasoning (VMR) program created technologies to automate the analysis of enemy-recorded photos and videos and to identify, within minutes, key information related to the content. This included identification of individuals within the image (who), enumeration of the objects within the image and their attributes (what), and determining the image's geospatial location and time frame (where and when). Large data stores of enemy photos and video are available but cannot be easily leveraged by a warfighter or analyst attempting to understand a specific new image in a timely fashion. The VMR program developed technology to enable users to gain insights rapidly through application of highly parallelized image analysis techniques that can process the imagery in massive distributed image stores. VMR technology serves as a force-multiplier by rapidly and automatically extracting tactically relevant information and alerting the analyst to scenes that warrant the analyst's expert attention. FY 2015 Accomplishments: - Included mechanisms for technical users to add new computer vision algorithms to the system. - Provided a quantified level of performance to show the advantage of multi-algorithm reasoning versus a single-algorithm approach. - Delivered robust full-featured Version 1.0 to National Media Exploitation Center (NMEC), FBI, AFRL, and other Government agencies as transition products.		6.104	-
Accomplishments/Planned Programs Subtotals		115.512	142.247
C. Other Program Funding Summary (\$ in Millions)			
N/A			
Remarks			
D. Acquisition Strategy			
N/A			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / <i>TACTICAL TECHNOLOGY</i>	Project (Number/Name) TT-13 / <i>NETWORK CENTRIC ENABLING TECHNOLOGY</i>

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>					R-1 Program Element (Number/Name) PE 0602715E / <i>MATERIALS AND BIOLOGICAL TECHNOLOGY</i>							
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	144.409	206.115	220.456	-	220.456	233.910	254.357	262.098	266.659	-	-
MBT-01: <i>MATERIALS PROCESSING TECHNOLOGY</i>	-	90.101	124.172	121.703	-	121.703	110.492	118.560	121.928	125.928	-	-
MBT-02: <i>BIOLOGICALLY BASED MATERIALS AND DEVICES</i>	-	54.308	81.943	98.753	-	98.753	123.418	135.797	140.170	140.731	-	-

A. Mission Description and Budget Item Justification

This program element is budgeted in the Applied Research Budget Activity because its objective is to develop material, biological and energy technologies that make possible a wide range of new military capabilities.

The major goal of the Materials Processing Technology project is to develop novel materials, materials processing techniques, mathematical models and fabrication strategies for advanced materials, devices and components that will lower the cost, increase the performance, and/or enable new missions for military platforms and systems. Included in this project are efforts across a wide range of materials including structural materials and devices, functional materials and devices, energetic materials and devices, low distortion optical lenses, and materials that enable new propulsion concepts for land, sea, and space vehicles.

The Biologically Based Materials and Devices project acknowledges the growing and pervasive influence of the biological sciences on the development of new DoD capabilities. This influence extends throughout the development of new materials, devices, and processes and relies on the integration of biological breakthroughs with those in engineering and the physical sciences. Contained in this project are thrusts in the application of biomimetic materials and devices for Defense, the use of biology's unique fabrication capabilities to produce structures that cannot be made any other way, the application of materials in biological applications, and the development of manufacturing tools that use biological components and processes for materials synthesis. This project also includes major efforts aimed at integrating biological and digital sensing methodologies and maintaining human combat performance despite the extraordinary stressors of combat. Finally, this thrust will develop new cognitive therapeutics, investigate the role of complexity in biological systems, and explore neuroscience technologies.

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>	R-1 Program Element (Number/Name) PE 0602715E / <i>MATERIALS AND BIOLOGICAL TECHNOLOGY</i>

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	150.389	220.115	263.319	-	263.319
Current President's Budget	144.409	206.115	220.456	-	220.456
Total Adjustments	-5.980	-14.000	-42.863	-	-42.863
• Congressional General Reductions	0.000	0.000			
• Congressional Directed Reductions	0.000	-14.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	-1.400	0.000			
• SBIR/STTR Transfer	-4.580	0.000			
• TotalOtherAdjustments	-	-	-42.863	-	-42.863

Change Summary Explanation

FY 2015: Decrease reflects reprogrammings and the SBIR/STTR transfer.

FY 2016: Decrease reflects congressional reduction.

FY 2017: Decrease reflects a reduction to Materials Processing and Manufacturing efforts and completion of the Manufacturable Gradient Index Optics (M-GRIN) program.

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY				Project (Number/Name) MBT-01 / MATERIALS PROCESSING TECHNOLOGY			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
MBT-01: MATERIALS PROCESSING TECHNOLOGY	-	90.101	124.172	121.703	-	121.703	110.492	118.560	121.928	125.928	-	-

A. Mission Description and Budget Item Justification

The major goal of the Materials Processing Technology project is to develop novel materials, materials processing techniques, mathematical models and fabrication strategies for advanced materials, devices and components that will lower the cost, increase the performance, and/or enable new missions for military platforms and systems. Included in this project are efforts across a wide range of materials including structural materials and devices, functional materials and devices, energetic materials and devices, low distortion optical lenses, and materials that enable new propulsion concepts for land, sea, and space vehicles.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Materials Processing and Manufacturing Description: The Materials Processing and Manufacturing thrust is exploring new manufacturing and processing approaches that will dramatically lower the cost and decrease the time required to fabricate DoD systems. It will also develop approaches that yield new materials and materials capabilities that cannot be made through conventional processing approaches as well as address efficient, low-volume manufacturing. As a result of recent advances in manufacturing techniques (3D printing, manufacture on demand, etc.) and the push towards programmable hardware in embedded systems, the development cycle from design to production of both hardware and software is severely bottlenecked at the design phase. Further research within this thrust, will create methods to translate natural inputs into software code and mechanical design. This process will complete underspecified designs when possible and initiate an iterative dialog with a human to specify details as needed and actively suggest changes to designers when the intended design cannot operate within the required specifications. FY 2015 Accomplishments: - Demonstrated integrated, physics-based, location-specific computational tools that predict the thermal history, residual stress, residual distortion, and microstructure of In718 alloys produced by direct metal laser sintering (DMLS). - Implemented in-process quality assurance (IPQA) sensors and technology capable of capturing DMLS processing data and initiated development of optimized capture of real-time data at appropriate resolutions to forecast article quality. - Demonstrated initial operational phenomenological metallurgical models that link electron beam direct manufacturing (EBDM) process parameters to microstructure and material properties for location-specific prediction of ultimate tensile strength throughout a built structure. - Demonstrated automated X-Y-Z wire position control system based on real-time, fast rate, solid-state backscattered electron sensor system. - Simulated high-fidelity probabilistic process window (including tails) for bonded composite structures using Monte Carlo techniques and a priori knowledge of process variables.	18.479	20.387	15.234

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Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY		Project (Number/Name) MBT-01 / MATERIALS PROCESSING TECHNOLOGY	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
- Completed verified 2D and 3D bonded composite pi-joint structure models. - Established interoperable process-material model assessment framework, and curated and standardized a data management system to capture and store data from materials and manufacturing research. FY 2016 Plans: - Complete design of experiments-optimized model for the probabilistic process model. - Demonstrate predictive capability of the probabilistic process model. - Complete optimized phenomenological yield strength model for electron beam additive manufacturing (EBAM). - Complete neural network and genetic numerical analysis for EBAM process. FY 2017 Plans: - Complete verification and validation of probabilistic processing model suite. - Validate phenomenological model framework. - Demonstrate rapid qualification capability on demonstration components.					
Title: Multifunctional Materials and Structures Description: The Multifunctional Materials and Structures thrust is developing materials, materials processing, and structures that are explicitly tailored for multiple functions and/or unique mechanical properties. One goal of this research is the ability to design, develop, and demonstrate materials with combinations of properties that are normally orthogonal (e.g., damage tolerance and biocompatibility). This capability will ultimately lead to enhanced lethality, survivability, and performance in future DoD platforms. This thrust will also include the exploration and development of dynamic models of complex systems across scale and develop new methodologies for understanding, architecting, and engineering complex systems. These computational tools will link material properties to physics across multiple length scales (from molecule to part) and provide the ability to model and exploit complexity, such as hierarchy and strongly correlated effects, in structural and functional materials. Development efforts under this thrust include reactive structures that can serve as both structure and explosive for lightweight munitions, novel materials and surfaces that are designed to adapt structural or functional properties to environmental and/or tactical threat conditions, and new thin film material deposition processes to improve the performance of surface dominated properties (friction, wear, and membrane permeability). In addition, this thrust will also explore new cost effective processes for ensuring DoD accessibility to future advanced materials. Examples of DoD applications that will benefit from these material developments include lower weight and higher performance aircraft, turbines with enhanced efficiency, erosion-resistant rotor blades, and high-temperature materials for operation in hypersonic environments. FY 2015 Accomplishments: - Experimentally validated computational models of low temperature thin-film growth. - Integrated in situ thin film characterization techniques for real-time qualitative and quantitative analysis of growth processes.			18.748	28.085	24.158

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY		Project (Number/Name) MBT-01 / MATERIALS PROCESSING TECHNOLOGY	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
- Demonstrated deposition of thin film challenge material on a substrate at low temperature. - Improved film quality and properties by adjusting process component parameters/integration strategy. - Generated design intent and the initial materials solution for a baseline hypersonic flight trajectory. - Established and populated the data warehouse for initial boost-glide aeroshell data. - Developed an initial framework for modeling complex systems made from tailorable feedstock materials and forming processes applicable to many domains. FY 2016 Plans: - Deliver thin film and coating materials with technical summaries to transition partners, Army Research Office and the Naval Research Laboratory. - Demonstrate initial integrated material, process, design, and manufacturing tool demonstrations for hypersonic hot structure aeroshell. - Create material system development and design framework, and link material informatics results to identify aeroshell mission performance drivers. - Generate a sub-component design concept and a sub-element design for hypersonic hot structure aeroshell. - Establish an independent test and evaluation capability for hypersonic hot structure aeroshell. - Identify candidate reinforced matrix compounds for enabling multiple platforms to be manufactured from a single tailorable feedstock material. - Identify reconfigurable forming technologies for the rapid, cost effective manufacture of complex shapes from matrix compounds reinforced with short, aligned elements. FY 2017 Plans: - Demonstrate an aligned and tailorable material feedstock that meets or exceeds state of the art aerospace materials performance. - Demonstrate a reconfigurable forming method that maintains alignment and distribution in short element reinforced matrix compounds when formed into complex shapes for DoD parts. - Demonstrate that a multifunctional element can be incorporated into the feed stock and maintain performance. - Demonstrate that a multifunctional component can be formed without degradation of performance in either the structural or functional component. - Create a cost model that assesses cost competitiveness and rate insensitivity of the new material format and forming process. - Establish process limits of forming capabilities.					
Title: Materials for Force Protection			16.223	25.353	27.361
Description: The Materials for Force Protection thrust is developing novel materials and materials systems that will greatly enhance performance against ballistic, blast, and chemical threats across the full spectrum of warfighter environments. Included					

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY		Project (Number/Name) MBT-01 / MATERIALS PROCESSING TECHNOLOGY	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
in this thrust are energy management and armor approaches to address explosively formed projectiles and shaped charges as well as new novel approaches for containment and remediation of chemical agent threats. The thrust will also focus on novel topological concepts as well as entirely new structural designs and chemistries that will afford enhanced, sustainable protection, and functionality at reduced weight and/or cost. FY 2015 Accomplishments: - Demonstrated at least 30% enhancement in opaque vehicle ballistic armor performance for combined bullet-frag threats over state-of-the-art fielded designs. - Demonstrated capability, based on small arms threat results, to achieve at least 30% enhancement in opaque vehicle ballistic armor performance to defeat bullets from heavier weapons. - Developed capability, based on results of feasibility study, to achieve 2x enhancement in opaque vehicle ballistic armor performance for multiple threats in an integrated armor design. - Developed and demonstrated ability of monohull design to spread impulsive load from enhanced (> 2x impulsive load) underbody blast and prevent breach at equivalent weight to current underbody structures. - Integrated energy absorbing materials and components into passive hierarchical energy absorbing systems characteristic of various vehicle weight classes and demonstrated capability to reduce by > 2x the combined effects of local and global impulse in underbody blast events. - Demonstrated capability to reduce by > 2x the combined effects of local and global impulse in active counter impulse systems characteristic of medium vehicle weights in underbody blast events. - Demonstrated capability to reduce by > 4x the effects of both local and global impulse by combining hierarchical passive energy absorbing systems into an integrated system characteristic of light and medium vehicle weight class in underbody blast events. - Explored novel approaches to chemical remediation of organic compounds with a focus on approaches that utilize readily available reagents (e.g., soil, water, and air). - Developed modeling capability for predicting material properties relationships such as density, strength, and toughness in hierarchical structures. - Initiated the development of knowledge-based tools to enable computational design and discovery of complex synthetic chemistry reaction pathways. - Initiated the design of a user interface for exploiting computational synthetic chemistry to predict complex reaction pathways. FY 2016 Plans: - Validate chemical remediation approaches against a series of DoD-relevant model compounds. - Demonstrate feasibility for achieving an efficiency of chemical agent remediation/conversion of > 99%. - Expand computational methods for reaction pathway design of structurally simple active pharmaceutical ingredients (APIs) such as ibuprofen and atropine.					

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY	Project (Number/Name) MBT-01 / MATERIALS PROCESSING TECHNOLOGY	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Demonstrate continuous synthesis of APIs such as nevirapine and hydroxychloroquine. FY 2017 Plans: - Validate in-line analytical monitoring of newly developed chemical remediation approaches. - Increase chemical remediation/conversion of DoD-relevant model compounds to 99.9%. - Initiate designs for extension of small-scale, continuous flow molecular syntheses to metric ton/year equivalent. - Demonstrate the synthesis of one challenge molecule in a fully automated system.			
Title: Functional Materials and Devices Description: The Functional Materials and Devices thrust is developing advanced materials and components that can improve the performance of a wide variety of functional devices for DoD sensing, imaging, and communication applications. One focus area under this thrust is the development of improved transductional materials that convert one form of energy to another (i.e., thermal to electrical, magnetic to electrical, etc.). Improvements in transductional materials and devices require deliberate control of material structure at the scale of the relevant phenomena. This thrust leverages advances in multi-physics modeling to identify and predict optimal material and device designs for a broad range of DoD applications. Examples of DoD applications that will benefit from advanced transductional materials include low size, weight and power (SWaP) thermoelectric coolers for DoD infrared sensors and compact RF antennas. FY 2015 Accomplishments: - Began the identification of DoD application-specific system specifications that will provide performance requirements for thermoelectric material development efforts. - Initiated study of novel power electronic circuit topologies to take advantage of emerging multiferroic materials for reduced size and weight. FY 2016 Plans: - Initiate the development of an open source model architecture and platform applicable for multiple transductional material domains (e.g. thermoelectric, magnetoelectric, multiferroic). - Continue the identification of DoD application-specific system specifications that will provide performance requirements for thermoelectric material development efforts. - Begin development of a multi-physics transductional material modeling capability that incorporates interface modeling and phonon engineering. - Design, fabricate and characterize thermoelectric materials and devices with improved performance metrics over the state-of-the-art.		6.000	13.734
			14.680

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY	Project (Number/Name) MBT-01 / MATERIALS PROCESSING TECHNOLOGY	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Design, fabricate and characterize materials and devices based on multiferroic or phase change materials with improved performance metrics over the state-of-the-art. FY 2017 Plans: - Finalize development of multi-physics transductional material modeling capability that incorporates interface modeling and phonon engineering. - Deliver proof of concept thermoelectric devices with improved performance over the state-of-the-art. - Deliver proof of concept devices based on multiferroic or phase change materials with improved performance over the state-of-the-art.			
Title: Reconfigurable Structures Description: In the Reconfigurable Structures thrust, new combinations of advanced materials, devices, structural architectures, and platforms are being developed to allow military systems to adapt to changing mission requirements and unpredictable environments. This includes the demonstration of new materials and devices that will enable the military to function more effectively in the urban theater of operations. In addition, this thrust will develop a principled, scientific basis for improved robotic mobility, manipulation, and supervised autonomy; and, leverage these results to develop and demonstrate innovative robot design tools, fabrication methods, and control methodologies. One specific objective of this thrust is to create the scientific basis for understanding, modeling, developing, testing and evaluating autonomous systems with one or more human supervisors, and one or more remote physical agents. Another thrust is the development of architectures that harness systems and human organizations working collaboratively. FY 2015 Accomplishments: - Investigated new control algorithms to enable sensing and processing for fast autonomous maneuvers in cluttered environments. - Designed platforms for low-Size, Weight and Power (SWaP) experimentation involving fast autonomous maneuvers. FY 2016 Plans: - Determine limits for GPS free navigation for short duration missions. - Model and develop behavioral controls to enable an Intelligence Surveillance and Reconnaissance (ISR) mission in a moderate-clutter environment. - Exploit novel mathematical tools and techniques for understanding the fundamentals of design science and design phenomena in complex systems and systems-of-systems. - Investigate architectures that harness systems and human organizations working together. FY 2017 Plans: - Develop representations and behaviors that enable an ISR mission in a high-clutter environment.		11.337	17.694
			23.310

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY	Project (Number/Name) MBT-01 / MATERIALS PROCESSING TECHNOLOGY		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Establish new paradigms for how systems and their constituent modules are represented, manipulated, integrated, and optimized. - Demonstrate management of complexity to enable inverse design of systems and capabilities.				
Title: Compact Neutron Sources Description: The Compact Neutron Sources thrust will develop the platform technologies for revolutionary portable energetic sources for in-field sensing, detection, and imaging. A focus of this thrust will be the development of compact neutron sources. Today's neutron imaging technology allows for unique sensing modalities that can currently only be performed at facility-sized installations. The research and development pursued under this thrust will enable the use of neutron imaging and detection in the field at time-scales and logistical footprints compatible with DoD missions. Multiple component technologies, such as new multi-functional materials with tuned physical and electrical characteristics and high-efficiency ion sources, will be developed and integrated in laboratory demonstration test beds. FY 2015 Accomplishments: - Developed and refined notional high-voltage particle accelerator system architectures for neutron production. - Designed components with 10-100x performance in key metrics as determined by system architecture requirements. - Developed and used high-performance design tools to conduct design and feasibility studies on accelerator and plasma components. FY 2016 Plans: - Incorporate technical findings from component design into expected performance metrics for integrated accelerators. - Refine components and begin integration into demonstration neutron source testbed. - Use component performance tests for design tool validation and development. FY 2017 Plans: - Identify successful compact neutron source components and integrate them into prototype systems. - Perform initial integrated compact neutron source prototype testing.		11.500	15.854	16.960
Title: Manufacturable Gradient Index Optics (M-GRIN) Description: The Manufacturable Gradient Index Optics (M-GRIN) program seeks to advance the development of gradient index optics (GRIN) lenses from a Technology Readiness Level (TRL) 3 to a Manufacturing Readiness Level (MRL) 6. The program will expand the application of GRIN by providing compact, lightweight, and cost-effective optical systems with controlled dispersion and aberrations that will replace large assemblies of conventional lenses. The ability to create entirely new optical materials and surfaces creates the potential for new or significantly improved military optical applications, such as solar concentrators, portable designators, highly efficient fiber optics, and imaging systems. The program also seeks to extend GRIN manufacturing		7.814	3.065	-

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY	Project (Number/Name) MBT-01 / MATERIALS PROCESSING TECHNOLOGY	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
technologies to glass, ceramic, and other inorganic materials in order to allow for small, lightweight, customized optical elements for mid-wave and long-wave infrared (MWIR and LWIR) applications. A key component of the program is to develop new design tools that enable optics designers to incorporate dynamic material properties, fabrication methods, and manufacturing tolerances. The integration of new materials, design tools, and manufacturing processes will enable previously unattainable 3-D optical designs to be manufactured. This new manufacturing paradigm will enable flexible production of GRIN optics in quantities of one unit to thousands of units. FY 2015 Accomplishments: - Completed GRIN lens production scale-up and demonstrated process control as measured against target yield and cost to enable sustainable manufacturing. - Upgraded design tools and expanded potential user pool from advanced to mid-level optical designers, through upgrades and improvements of the GRIN design modules, to provide user-friendly interface for customers. - Completed expansion of design tools to add 3D and arbitrary gradients as well as improve computational efficiency. - Completed process characterization and control to achieve target yields and turn-around times. - Initiated prototype builds to demonstrate system performance and/or size, weight and power (SWaP) improvement from GRIN optical systems. - Initiated thermal model and implement in optical system design to mitigate thermal effect on optical performance. - Initiated demonstration of rapid redevelopment/prototyping capability. FY 2016 Plans: - Complete prototype builds to demonstrate system performance and/or SWaP improvement from GRIN optical systems. - Complete thermal model and implement in optical system design to mitigate thermal effect on optical performance. - Complete demonstration of rapid redevelopment/prototyping capability.			
Accomplishments/Planned Programs Subtotals		90.101	124.172
C. Other Program Funding Summary (\$ in Millions)			
N/A			
Remarks			
D. Acquisition Strategy			
N/A			
E. Performance Metrics			
Specific programmatic performance metrics are listed above in the program accomplishments and plans section.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY				Project (Number/Name) MBT-02 / BIOLOGICALLY BASED MATERIALS AND DEVICES			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
MBT-02: BIOLOGICALLY BASED MATERIALS AND DEVICES	-	54.308	81.943	98.753	-	98.753	123.418	135.797	140.170	140.731	-	-

A. Mission Description and Budget Item Justification

This project acknowledges the growing and pervasive influence of the biological sciences on the development of new DoD capabilities. This influence extends throughout the development of new materials, devices, and processes and relies on the integration of biological breakthroughs with those in engineering and the physical sciences. Contained in this project are thrusts that apply biology's unique fabrication and manufacturing capabilities to produce novel chemicals and materials at scale, as well as research to develop new high-throughput methods and devices to analyze biological changes at the cellular and molecular level. This project also includes major efforts aimed at integrating biological, computational, and digital sensing methodologies to explore neuroscience technology and maintain human combat performance.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: BioDesign	13.916	13.500	13.582
Description: BioDesign will employ system engineering methods in combination with advances in biological and chemical technologies to create novel methods for threat response. This thrust will develop new high-throughput technologies for monitoring the function of cellular machinery at the molecular level and the response(s) of that machinery to physical, chemical, or biological threats. While conventional approaches typically require decades of research, new high-throughput approaches will permit rapid assessment of the impact of known or unknown threats on identified biomolecules and cell function. Successful research in this thrust will both reduce the time required to understand the mechanism of action for new pharmaceutical compounds and enhance response capabilities for emerging and engineered threats.			
FY 2015 Accomplishments: - Utilized high throughput approaches to characterize intracellular components and mechanistic interactions that reveal the effects of challenge compounds on intracellular machinery. - Demonstrated high throughput methods using cells of human origin. - Demonstrated the ability to identify intracellular components and events that occur hours after the application of a challenge compound. - Demonstrated the ability to localize relevant molecules and events to one intracellular compartment (membrane, nucleus, or cytoplasm) upon the application of a challenge compound.			

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY	Project (Number/Name) MBT-02 / BIOLOGICALLY BASED MATERIALS AND DEVICES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Reconstructed and confirmed greater than 20 percent of the molecules and mechanistic events that comprise the canonical mechanism of action for a demonstration compound which has been applied to cells. FY 2016 Plans: - Demonstrate the ability to localize relevant molecules and events to one or more intracellular compartment(s) (e.g., membrane, nucleus, or cytoplasm) upon the application of a challenge compound. - Demonstrate the ability to identify intracellular components and events that occur within minutes after the application of a challenge compound. - Reconstruct and confirm greater than 60 percent of the molecules and mechanistic events that comprise the canonical mechanism of action for a demonstration compound which has been applied to cells. FY 2017 Plans: - Continue to demonstrate the ability to localize relevant molecules and events to one or more intracellular compartment(s) (e.g., membrane, nucleus, or cytoplasm) upon the application of a challenge compound. - Demonstrate the ability to identify intracellular components and events that occur within seconds after the application of a challenge compound. - Reconstruct and confirm greater than 80 percent of the molecules and mechanistic events that comprise the canonical mechanism of action for a demonstration compound which has been applied to cells.				
Title: Living Foundries Description: The goal of the Living Foundries program is to create a revolutionary, biologically-based manufacturing platform for the DoD and the Nation. With its ability to perform complex chemistries, be flexibly programmed through DNA code, scale, adapt to changing environments, and self-repair, biology represents one of the most powerful manufacturing platforms known. Living Foundries seeks to develop the foundational technological infrastructure to transform biology into an engineering practice, speeding the biological design-build-test-learn cycle and expanding the complexity of systems that can be engineered. Ultimately, Living Foundries aims to provide game-changing manufacturing paradigms for the DoD, enabling adaptable, on-demand production of critical and high-value molecules. Research thrusts will focus on the development and demonstration of open technology platforms to prove out capabilities for rapid (months vs. years) design and construction of new bio-production systems. The result will be an integrated, modular infrastructure across the areas of design, fabrication, debugging, analysis, optimization, and validation -- spanning the entire development life-cycle and enabling the ability to rapidly assess and improve designs. Key to success will be tight coupling of computational design, fabrication of systems, debugging using multiple characterization data types, analysis, and further development such that iterative design and experimentation will be accurate, efficient and controlled. Demonstration platforms will be challenged to build a variety of DoD-relevant, novel molecules with complex functionalities, such as synthesis of advanced, functional chemicals,		24.838	28.900	27.700

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY	Project (Number/Name) MBT-02 / BIOLOGICALLY BASED MATERIALS AND DEVICES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
materials precursors, and polymers (e.g., those tolerant of harsh environments). This program has basic research efforts funded in PE 0601101E, Project TRS-01.				
FY 2015 Accomplishments: - Expanded the capabilities of the rapid design and prototyping infrastructure to target molecules that are difficult or costly to produce using traditional synthesis mechanisms. - Expanded access and experimental scale to promote the production capabilities of rapid design and prototyping facilities infrastructure. - Began establishing the efficacy of the integrated design-build-test-learn feedback cycle for forward design and rapid optimization of target molecules via the prototyping facility's established processes.				
FY 2016 Plans: - Demonstrate the ability of infrastructure pipelines to rapidly generate target molecules. - Initiate pressure tests of the Foundries to test capabilities of the design and prototyping pipelines in demonstrating the speed, breadth, and efficacy of the infrastructure designs. - Implement learn capabilities into design algorithms based on testing and characterization of previously prototyped targets in order to improve the processes. - Improve forward design and rapid optimization of target molecules via the prototyping facility's established processes. - Initiate development of computational infrastructure to link component technologies and enable end-to-end process monitoring.				
FY 2017 Plans: - Further advance infrastructure pipelines capable of rapidly prototyping and generating DoD-relevant molecules, with significant emphasis on system integration, throughput, and process optimization. - Continue pressure tests of the infrastructure facilities to test capabilities of the design and prototyping pipelines in demonstrating the speed, breadth, and efficacy of the infrastructure designs. - Test the ability to produce ten molecules that are relevant to the DoD. - Incorporate learn capabilities into design algorithms based on testing and characterization of previously prototyped targets in order to improve the processes. - Begin developing the infrastructure pipelines to prototype production of known, but currently biologically inaccessible, molecules.				
Title: Adaptive Immunomodulation-Based Therapeutics		12.554	22.000	22.971
Description: The Adaptive Immunomodulation-Based Therapeutics program will develop platform technologies to interrogate and define the biological pathways that modulate the immune response and critical organ function. One approach to achieve this capability will require the development of new tools to stimulate and measure responses of the nervous system in order to				

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY	Project (Number/Name) MBT-02 / BIOLOGICALLY BASED MATERIALS AND DEVICES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
map the bioelectric code modulates. This program will also identify immune function correlates for health and early detection of disease. An additional approach involves characterizing the host response in patients with severe infections, and developing a quantitative framework that can be used to guide modulation of the immune response. Algorithms will be developed to evaluate and predict various physiological conditions within an individual. Advances made under the Adaptive Immunomodulation-Based Therapeutics program will improve our response capability against severe infectious diseases and biological threats and offer new avenues for treating disease or organ function. FY 2015 Accomplishments: - Initiated development of capabilities to characterize the neural-immune interface, including real-time measurement of biomarkers. - Began identifying novel, actionable targets for neural immune modulation. - Started identifying specific neuro-visceral circuits which can be targeted by electrical, optical, ultrasonic, or other novel stimulation approaches to modulate function. FY 2016 Plans: - Develop novel interface technologies to monitor and stimulate peripheral nerves to selectively alter organ function. - Compare specificity of novel interface technologies with state of the art whole-nerve stimulation devices. - Define input/output models of mammalian autonomic functions such as the immune system and/or the autonomic stress response. - Identify peripheral intervention points and modulation parameters for control of mammalian autonomic function for improving health or treating disease. - Develop multi-site electrode array and stimulator to improve targeting of vagal nerve stimulation. FY 2017 Plans: - Initiate demonstrations of advanced peripheral nerve interface technologies in small and large animal models to improve inflammatory and neuropsychiatric disease outcomes. - Develop computational models to simulate noninvasive peripheral nerve modulation approaches for desired physiological outcome. - Elucidate mechanisms of action for peripheral nerve modulation via noninvasive techniques. - Identify panels of relevant biomarkers that are indicative of diseased state and provide a reliable and specific surrogate measure to track physiological response to peripheral nerve modulation.				
Title: Biological-Computational Platforms		-	8.468	10.382
Description: The Biological-Computational Platforms program is a multi-disciplinary effort that combines neuroscience, biology, advanced computer science, mathematical modeling, and novel interfaces to create hybrid biological-computational platforms				

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Appropriation/Budget Activity 0400 / 2		R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY		Project (Number/Name) MBT-02 / BIOLOGICALLY BASED MATERIALS AND DEVICES	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
for DoD applications. The program will research and develop tools that enable improved integration of biological processes and computing systems for facilitating perception, communication, and control. Novel hardware and software developed through this program will be able to operate on relevant environmental, physiological and neural information. The ultimate goal of this work is to develop hybrid biological-computational interfaces that optimize human-computer effectiveness. FY 2016 Plans: - Analyze architectures and systems for utilizing complex biological signals generalizable across users. - Investigate new approaches for neural sensor design to provide high spatial and temporal resolution without the use of an invasive microelectrode implant. - Begin studying approaches to transform neural representations of meaning, content and intentionality to new communications protocols with devices and computers. FY 2017 Plans: - Integrate multimodal input processing and demonstrate successful capacity for real-time feedback signaling to enable task performance. - Facilitate neurophysiologic-computer interfaces that enable direct control of multiple aspects of fixed facilities and mobile platforms. - Identify and quantify parameters of normal task performance involving fixed and mobile platforms. - Develop methods for assembling and rapidly deploying suites of physiologic and environmental sensors for integration with machine learning.					
Title: Biological Robustness in Complex Settings (BRICS) Description: The Biological Robustness in Complex Settings (BRICS) program will leverage newly developed technologies to enable radical new approaches for engineering biology. This area will focus on the creation of enabling technologies that will facilitate the development and integration of fundamental tools and methods being explored under the BRICS program. Research within this area may focus on the development of tools for genetic engineering of traditionally intractable species and tools for high-resolution characterization of biological communities. Ultimately, this area seeks to integrate the fundamental component technologies developed under PE 0601101E, TRS-01 into a platform technology capable of engineering robust, stable, and safe communities for the prevention and treatment of disease. This program has basic research efforts funded in PE 0601101E, Project TRS-01. FY 2016 Plans: - Develop technologies to design and build biological pathways that will function in undomesticated microbial species from a wide range of phyla (prokaryotic or eukaryotic).			-	9.075	10.200

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY	Project (Number/Name) MBT-02 / BIOLOGICALLY BASED MATERIALS AND DEVICES		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Develop theoretical tools that allow the prediction of metrics of behavior and community dynamics, such as species composition, resource utilization, and small molecule communication within a multi-species consortium. - Fabricate generalizable culture substrates that provide control over community structure and composition and support the growth of both prokaryotic and eukaryotic cells. FY 2017 Plans: - Integrate promising component technologies that may be readily adapted into a platform for engineering robust, stable, and safe biological communities. - Demonstrate reliable function of engineered microbial communities in complex laboratory environments. - Demonstrate potential for safe use of engineered consortia under conditions relevant to specific applications.				
Title: Enhancing Neuroplasticity Description: The Enhancing Neuroplasticity program will explore and develop stimulation methods and non-invasive devices to promote synaptic plasticity that is expected to impact higher cognitive functions. Key advances anticipated from this research will both create an anatomical and functional map of the underlying biological circuitry that mediates plasticity and optimize stimulation and training protocols to enable long-term retention. Once successfully identified, the underlying mechanisms of targeted plasticity training can be applied to a broad range of cognitive functions with the Department of Defense, including foreign language learning, or data and intelligence analysis. FY 2017 Plans: - Determine the effects of nerve stimulation parameters (amplitude, rate, and timing) on brain regions that modulate plasticity. - Compare effectiveness of deep and superficial nerve stimulation sites in promoting synaptic plasticity and improving performance on language learning tasks. - Demonstrate effects of training on tuning functions of neurons in auditory and speech areas of the brain. - Perform studies to compare neurophysiology and learning effects of invasive and noninvasive stimulators.		-	-	13.918
Title: Neuroscience Technologies Description: The Neuroscience Technologies thrust leveraged recent advances in neurophysiology, neuro-imaging, cognitive science, molecular biology, and modeling of complex systems to sustain and protect the cognitive functioning of the warfighter faced with challenging operational conditions. Warfighters experience a wide variety of operational stressors, both mental and physical, that degrade critical cognitive functions such as memory, learning, and decision making. These stressors also degrade the warfighter's ability to multitask, leading to decreased ability to respond quickly and effectively. Currently, the long-term impact of these stressors on the brain is unknown, both at the molecular and behavioral level. This thrust area investigated modern neuroscientific techniques to develop quantitative models of this impact and explored mechanisms to protect, maintain, complement, or restore physical and cognitive functioning during and after exposure to operational stressors. In addition, new		3.000	-	-

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Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602715E / MATERIALS AND BIOLOGICAL TECHNOLOGY	Project (Number/Name) MBT-02 / BIOLOGICALLY BASED MATERIALS AND DEVICES	

B. Accomplishments/Planned Programs (\$ in Millions)	FY 2015	FY 2016	FY 2017
approaches for using physiological and neural signals to make human-machine systems more time efficient and less workload intense were identified. <i>FY 2015 Accomplishments:</i> - Investigated methods to exploit recent advances in neurophysiology recording technologies, cognitive science, and engineering in conjunction with emerging solutions in neurally enabled human-machine interface technologies to characterize dynamics of human cognitive functions such as memory, learning, and decision making. - Exploited recent advances in computational analysis, systems identification, data intensive computing, and statistical inference methods to research novel computational tools for rapid analysis, validation, and integration of computational models of the brain. - Researched methods for joint computation and operations between biological systems and traditional digital computing systems.			
Accomplishments/Planned Programs Subtotals	54.308	81.943	98.753

C. Other Program Funding Summary (\$ in Millions)
N/A

Remarks

D. Acquisition Strategy
N/A

E. Performance Metrics
Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity					R-1 Program Element (Number/Name)							
0400: Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research					PE 0602716E / ELECTRONICS TECHNOLOGY							
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	169.690	174.798	221.911	-	221.911	234.424	236.582	233.270	245.370	-	-
ELT-01: ELECTRONICS TECHNOLOGY	-	169.690	174.798	221.911	-	221.911	234.424	236.582	233.270	245.370	-	-

A. Mission Description and Budget Item Justification

This program element is budgeted in the Applied Research budget activity because its objective is to develop electronics that make a wide range of military applications possible.

Advances in microelectronic device technologies, including digital, analog, photonic and MicroElectroMechanical Systems (MEMS) devices, continue to have significant impact in support of defense technologies for improved weapons effectiveness, improved intelligence capabilities and enhanced information superiority. The Electronics Technology program element supports the continued advancement of these technologies through the development of performance driven advanced capabilities, exceeding that available through commercial sources, in electronic, optoelectronic and MEMS devices, semiconductor device design and fabrication techniques, and new materials and material structures for device applications. A particular focus for this work is the exploitation of chip-scale heterogeneous integration technologies that permit the optimization of device and integrated module performance.

The phenomenal progress in current electronics and computer chips will face the fundamental limits of silicon technology in the early 21st century, a barrier that must be overcome in order for progress to continue. The program element will therefore explore alternatives to silicon-based electronics in the areas of new electronic devices. The program element will also explore new architectures to use devices of all types, new software to program the systems, and new methods to fabricate the chips. Approaches include nanotechnology, nanoelectronics, molecular electronics, spin-based electronics, quantum-computing, new circuit architectures optimizing these new devices, and new computer and electronic systems architectures. Projects will investigate the feasibility, design, and development of powerful information technology devices and systems using approaches for electronic device designs that extend beyond traditional Complementary Metal Oxide Semiconductor (CMOS) scaling, including non-silicon-based materials technologies to achieve low cost, reliable, fast and secure computing, communication, and storage systems. This investigation is aimed at developing new capabilities from promising directions in the design of information processing components using both inorganic and organic substrates, designs of components and systems leveraging quantum effects and chaos, and innovative approaches to computing designs incorporating these components for such applications as low cost seamless pervasive computing, ultra-fast computing, and sensing and actuation devices.

This project has five major thrusts: Electronics, Photonics, MicroElectroMechanical Systems, Architectures, Algorithms, and other Electronic Technology research.

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency				Date: February 2016		
Appropriation/Budget Activity 0400: Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research		R-1 Program Element (Number/Name) PE 0602716E / ELECTRONICS TECHNOLOGY				
B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	
Previous President's Budget	169.203	174.798	170.783	-	170.783	
Current President's Budget	169.690	174.798	221.911	-	221.911	
Total Adjustments	0.487	0.000	51.128	-	51.128	
• Congressional General Reductions	0.000	0.000				
• Congressional Directed Reductions	0.000	0.000				
• Congressional Rescissions	0.000	0.000				
• Congressional Adds	0.000	0.000				
• Congressional Directed Transfers	0.000	0.000				
• Reprogrammings	5.640	0.000				
• SBIR/STTR Transfer	-5.153	0.000				
• TotalOtherAdjustments	-	-	51.128	-	51.128	
Change Summary Explanation						
FY 2015: Increase reflects reprogrammings offset by the SBIR/STTR transfer.						
FY 2016: N/A						
FY 2017: Increase reflects initiation of new start programs: Limits of Thermal Sensors (LOTS) and Connect Everything, and expansion of several efforts supporting precision, navigation and timing and electromagnetic spectrum dominance.						
C. Accomplishments/Planned Programs (\$ in Millions)				FY 2015	FY 2016	FY 2017
Title: Adaptive Radio Frequency Technology (ART)				24.003	16.550	8.500
Description: There is a critical ongoing military need for flexible, affordable, and small size, weight and power (SWaP) real-time-adaptable military electromagnetic interfaces. The Adaptive Radio Frequency Technology (ART) program will provide the warfighter with a new, fully adaptive radio platform capable of sensing the electromagnetic and waveform environment in which it operates, making decisions on how to best communicate in that environment, and rapidly adapting its hardware to meet ever-changing requirements, while simultaneously significantly reducing the SWaP of such radio nodes. ART technology will also provide each warfighter, as well as small-scale unmanned platforms, with compact and efficient signal identification capabilities for next-generation cognitive communications, and sensing and electronic warfare applications. ART technology will also enable rapid radio platform deployment for new waveforms and changing operational requirements. The project will remove the separate design tasks needed for each unique Radio Frequency (RF) system, which will dramatically reduce the procurement and sustainment cost of military systems. ART aggregates the Feedback Linearized Microwave Amplifiers program, the Analog Spectral Processing program, and Chip Scale Spectrum Analyzers (CSSA) program, and initiates new thrusts in Cognitive Low-energy Signal Analysis and Sensing Integrated Circuits (CLASIC), and Radio-Frequency Field-Programmable Gate Arrays (RF-FPGA).						

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C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
<i>FY 2015 Accomplishments:</i> - Demonstrated a radio reconfigurable between five different RF systems using integrated phase-change switch and silicon germanium (SiGe) technologies. Phase change switch reliability improved to 400,000 cycles and power handling improved by 10X to nearly 1 watt. - Integrated a highly reconfigurable RF front-end into a commercial software defined radio board that broadened the user base for RF-FPGA technology and transitioned multiple RF-FPGA cognitive radios. - Demonstrated the ability to, without prior knowledge, classify 32 wireless communication signal types in a hand held form factor while consuming less than 10 mW of power. - Demonstrated an adaptable, fully integrated radio system that is small enough to be carried by a warfighter and is resistant to jamming. <i>FY 2016 Plans:</i> - Investigate transition paths for phase change switch technology including potential transitions into a commercial semiconductor foundry. - Investigate transition paths for RF-FPGA reconfigurable RF front-ends including supplying demo units to DoD end users and investigating commercial paths for supplying the technology to the DoD. - Increase power handling of phase change switch technology to > 1W and improve reliability to > 1 Million cycles to meet the performance requirements of military and commercial communications systems. - Demonstrate an RF front-end reconfigurable between five different RF systems with performance approaching (> 90%) that of a fixed point solution. <i>FY 2017 Plans:</i> - Finalize transition plans for a fully reconfigurable RF circuit technology at the component and system levels.				
<i>Title:</i> Diverse & Accessible Heterogeneous Integration (DAHI) <i>Description:</i> The scaling of silicon (Si) transistors to ever smaller dimensions has led to dramatic gains in processor performance over the past fifty years. In parallel, Integrated Circuits (IC) designers for RF circuits have leveraged the different material properties of compound semiconductor (CS) technologies such as indium phosphide (InP), gallium arsenide (GaAs), gallium nitride (GaN) and silicon-germanium (SiGe) to enable devices that operate at frequencies and powers difficult or impossible to achieve in Silicon. Historically, a designer would have to decide between the high density of Si circuits or the high performance of CS materials. Prior DARPA efforts have demonstrated the ability to achieve near-ideal "mix-and-match" capability for DoD circuit designers with limited demonstrations of the heterogeneous integration of silicon and InP technologies that far exceeded what can be accomplished with one technology alone. Specifically, the Compound Semiconductor Materials On Silicon (COSMOS) program enabled transistors of InP to be freely mixed with silicon complementary metal-oxide semiconductor (CMOS) circuits to obtain the benefits of both technologies (very high speed and very high circuit complexity/density, respectively). The Diverse &		29.400	16.983	11.500

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C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Accessible Heterogeneous Integration (DAHI) effort will take this capability to the next level, ultimately offering the seamless co-integration of a variety of semiconductor devices (for example, GaN, InP, GaAs, antimonide based Compound Semiconductors), microelectromechanical (MEMS) sensors and actuators, photonic devices (e.g., lasers, photo-detectors) and thermal management structures. This capability will revolutionize our ability to build true "systems on a chip" (SoCs) and allow dramatic size, weight and volume reductions while enabling higher performance such as power, bandwidth or dynamic range in our electronic systems for electronic warfare, communications and radar. In the Applied Research part of this program, high performance RF/optoelectronic/mixed-signal systems-on-a-chip (SoC) for specific DoD transition applications will be developed as a demonstration of the DAHI technology. To provide maximum benefit to the DoD, these processes will be transferred to a manufacturing flow and made available (with appropriate computer aided design support) to a wide variety of DoD laboratory, Federally Funded Research and Development Center (FFRDC), academic and industrial designers. Manufacturing yield and reliability of the DAHI technologies will be characterized and enhanced. This program has advanced technology development efforts funded in PE 0603739E, Project MT-15. FY 2015 Accomplishments: - Completed first run development of new CMOS-compatible processes to achieve heterogeneous integration with diverse types of compound semiconductor transistors, MEMS, and non-silicon photonic devices, including interconnect and thermal management approaches. - Developed wafer-bonding-based and assembly-based heterogeneous integration process technology, enabling the design of demonstration circuits. - Completed first manufacturing run demonstrating yield and reliability enhancement for multi-user foundry capability based on developed diverse heterogeneous integration processes. - Successfully created circuits using the DAHI process that represent a variety of next generation systems, such as radar, EW, and communications. These include Gallium Nitride (GAN) -Indium Phosphide (InP) differential and push-pull amplifiers, heterogeneously integrated RF/optoelectronic circuits, and integrated polyphase transmitter and voltage-controlled oscillator-amplifier chains using silicon CMOS, InP Heterojunction Bipolar Transistor (HBTs), and GaN High-Electron-Mobility Transistor (HEMTs). FY 2016 Plans: - Demonstrate heterogeneous integration of advanced node silicon CMOS processes achieved with diverse types of compound semiconductor transistors, MEMS, and non-silicon photonic devices, including interconnect and thermal management approaches. - Transition multi-user foundry interface to independent design service from proprietary foundry model to enable community access to diverse heterogeneous integration processes.				

UNCLASSIFIED

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C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Demonstrate sustainable model and accessibility via foundry/customer engagements, including detailed cost models and quotations. FY 2017 Plans: - Demonstrate heterogeneous integration process variant based on low cost Si interposer technology combining heterogeneously integrated multi-technology circuits with high Q passive technologies. - Demonstrate integration of emerging device technologies into established heterogeneous integration process flow with minimal process deviation.				
Title: Common Heterogeneous integration & IP reuse Strategies (CHIPS)* Description: *Formerly Fast and Big Mixed-Signal Designs (FAB) The scaling of silicon transistors to ever smaller dimensions has led to dramatic gains in processor performance over the past forty years. In parallel, IC designers for RF circuits have leveraged the different material properties of compound semiconductor (CS) technologies such as gallium arsenide (GaAs), gallium nitride (GaN) and silicon-germanium (SiGe) to enable devices that operate at frequencies and powers difficult or impossible to achieve in silicon. When integrated together the heterogeneous integration of these technologies has been demonstrated to far exceed what can be accomplished with any one technology alone. The process of integrating CS technologies on silicon currently requires that the silicon transistor dimension, or process node, be fixed which requires designs to be remade for various combinations of technology and process node, a costly and time consuming effort. This program will investigate the potential for a truly process-agnostic integration technology that is inclusive of any current or future circuit fabrication technology with a standardized interconnect topology. Such a technology platform will enable the design of individual circuit intellectual property (IP) blocks, such as low-noise amplifiers or analog-to-digital converters (ADC), with a goal of re-using them across applications and resulting in time and cost savings. Re-use will allow the DoD to spread the upfront design cost of these blocks over several designs instead of leveling the burden on a single program. Furthermore, the IP can be designed in the fabrication process best suited for the performance goals and evolve more quickly than larger, more expensive single-chip (monolithic) systems-on-a-chip. Through standardization of the interface, CHIPS will enable the DoD to leverage the advancements driven by the global semiconductor market rather than relying on a single on-shore foundry provider or on proprietary circuit designs owned by a few traditional prime performers. In the Applied Research part of this program, focus will be placed on the rapid development and insertion of microsystems utilizing the CHIPS technology. For example, the development of an ADC combining a SiGe circuit integrated with 14 nanometer Silicon CMOS will be explored. This program has advanced technology development efforts funded in PE 0603739E, Project MT-15. FY 2015 Accomplishments:		4.823	14.800	25.500

UNCLASSIFIED

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C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Determined the best choices for the RF and digital technologies and the best methods of co-integration (monolithic, through-silicon via (TSV) and interposer) in order to achieve program objectives, along with identifying partner(s) for fabrication and/or integration. - Began circuit design activities to determine performance benefits of new processes enabled by the program. - Studied the best technology for various RF functional blocks for optimal use of mixed technologies. - Investigated a methodology for enabling reuse of government funded or commercial IP and mechanisms for storing them for future use. - Initiated studies that investigated the benefits to development cycle and cost reduction for electronics IC s through internal IP reuse at a large defense contractor. FY 2016 Plans: - Continue to investigate choices for the RF and digital technologies and the best methods of co-integration (monolithic, through-silicon via (TSV) and interposer) in order to achieve program objectives, along with identifying partner(s) for fabrication and/or integration. - Continue to study the best technology for various RF functional blocks for optimal use of mixed technologies. - Investigate tradeoff matrix for various co-integration (monolithic, through-silicon via (TSV) and interposer) strategies for RF and digital technologies. - Develop a cost model to analyze the impact of IP reuse using insight gained from large defense contractor development cycle study. - Study the system level impact of IP re-use for the optimal use of RF mixed technology functional blocks. FY 2017 Plans: - Finalize potential standards definitions for high-bandwidth interfaces of CMOS chiplet-to-chip interconnections. - Study the system level impact of IP re-use for the optimal use of RF mixed technology functional blocks. - Initiate circuit demonstrations of chip-to-chip interconnects for CMOS chip stacks. - Initiate circuit demonstrations with heterogeneous integration of DOD IP blocks and commercial IP blocks. - Continue circuit design activities to determine performance benefits of new processes enabled by the program.				
Title: Direct On-Chip Digital Optical Synthesis (DODOS)		3.664	9.400	13.000
Description: The development of techniques for precise frequency control of RF and microwave radiation in the 1940's revolutionized modern warfare. Frequency control is the enabling technology for RADAR, satellite and terrestrial communications, and positioning and navigation technology, among many other core DoD capabilities. By comparison, frequency control at optical frequencies is relatively immature, comparable to the state-of-the-art of microwave control in the 1930's. The first practical demonstration of optical frequency synthesis, utilizing a self-referenced optical comb, was performed in 1999 and, since that time, the precision and accuracy of optical measurements has improved by four orders of magnitude, including the demonstration of				

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions) atomic clocks utilizing optical-frequency atomic transitions that far outperform existing technology based on microwave transitions. To date, however, optical frequency control has been constrained to laboratory experiments due to the large size, relative fragility, and high cost of optical comb-based synthesizers. Recent developments in self-referenced optical frequency combs in microscale resonators enable the development of a fully-integrated chip-scale optical frequency synthesizer. Ubiquitous low-cost robust optical frequency synthesis is expected to create a similar disruptive capability in optical technology as microwave frequency synthesis did in the 1940's, enabling high-bandwidth coherent optical communications, coherent synthesized-aperture LiDAR, portable high-accuracy atomic clocks, high-resolution standoff gas/toxin detection, and intrusion detection, among other foreseen applications. The Direct On-chip Digital Optical Synthesis (DODOS) program will integrate a diverse range of photonic and electronic components to create a microscale, high-accuracy optical frequency synthesizer, in a compact, robust package, suitable for deployment in a wide variety of mission-critical DoD applications. Significant challenges in the program include the integration of heterogeneous devices and materials that are incompatible with conventional high-volume manufacturing of integrated circuits, optimizing efficient on-chip pump lasers and high-bandwidth detectors, and developing high-precision microwave control electronics with low power consumption. Basic research for this program is funded within PE 0601101E, Project ES-01. FY 2015 Accomplishments: - Completed modeling and proof-of-concept experiments to validate low-threshold approaches to optical frequency combs. - Developed DODOS system architectures and integration approaches. FY 2016 Plans: - Validate device-level performance requirements, such as the control-loop bandwidths and optical link budget, needed to reach the DODOS program metrics at the system level. - Prototype critical photonic components in processes consistent with subsequent co-integration. - Demonstrate tabletop DODOS, utilizing microscale components compliant with Phase-1 Program objectives. FY 2017 Plans: - Validate prototype photonic integrated circuits containing all optical components required by the DODOS system architecture. - Implement off-chip electronics and algorithms and demonstrate DODOS electro-optic functionality. - Develop packaging techniques to co-integrate DODOS photonics and electronic control circuits.		FY 2015	FY 2016	FY 2017
Title: Arrays at Commercial Timescales (ACT) Description: Phased arrays are critical system components for high performance military electronics with widespread applications in communications, electronic warfare and radar. The DoD relies heavily on phased arrays to maintain technological superiority in nearly every theater of conflict. The DoD cannot update these high cost specialized arrays at the pace necessary to effectively		25.000	26.550	20.000

UNCLASSIFIED

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C. Accomplishments/Planned Programs (\$ in Millions) counter adversarial threats. The Arrays at Commercial Timescales (ACT) program fills this gap through the use of commercial-of-the-shelf components that can undergo technology refresh far more frequently in response to a continually changing threat environment. ACT will develop adaptive and standardized digital-at-every-element arrays that can replace static analog beamformers with cost effective digital array systems capable of a yearly technology refresh. By doing so, phased arrays will become ubiquitous throughout the DoD, moving onto many platforms for which phased arrays had been previously prohibitively expensive to develop or maintain.		FY 2015	FY 2016	FY 2017
FY 2015 Accomplishments: - Continued development and integration of common hardware components, such as application specific integrated circuits and field programmable gate arrays, for a wide range of phased array antenna systems; finalized initial designs and began fabrication for ACT demonstration units to be completed and tested in FY16. - Signed Memorandum of Understanding (MOU) between the Army Research Lab (ARL) and DARPA to support the performance testing of ACT Common Modules for potential Army transition opportunities. - Continued to identify government application spaces and transition paths for the ACT Common Module and reconfigurable antenna apertures to include the planned use of ACT technology components in a new AFRL program. - Finalized design and started fabrication of application specific integrated circuits (ASIC) in 32 nanometer (nm) CMOS, 65 nm CMOS and Silicon Germanium (SiGe) technologies that enable commonality across a wide range of phased array platforms. - Performed first measurements on fabricated SiGe ASICS demonstrating RF filter performance and RF amplifier performance as predicted by modeling. FY 2016 Plans: - Demonstrate Common Module hardware viability through government testing of delivered hardware components in a government furnished system platform. - Organize an ACT common module demonstration day to inform potential transition partners and industrial users on the measured performance of the Phase I modules. - Investigate the benefits of and develop plans and preliminary designs for upgrading the ACT Common Module in a state-of-the-art fabrication process. - Demonstrate a fundamental element of a reconfigurable antenna array and define a list of personalities possible to cover the DoD application space. - Continue to identify government application spaces and transition paths for the ACT Common Module and reconfigurable antenna apertures. FY 2017 Plans: - Develop the ACT common module using an advanced process node and demonstrate the performance improvement compared to the common module developed with an earlier node in Phase I.				

UNCLASSIFIED

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Demonstrate rapid technology refresh of the common modules developed in Phase 1. - Drive the ACT common module technology transition process by gathering and sharing test results with potential users. - Develop a reconfigurable antenna array using 16 elements that cover multiple frequency bands (S, X bands) using the technology demonstrated earlier in the program.				
Title: High power Amplifier using Vacuum electronics for Overmatch Capability (HAVOC) Description: The effectiveness of combat operations across all domains increasingly depends on our ability to control and exploit the electromagnetic (EM) spectrum, and to deny its use to our adversaries. Below 30 GHz, the proliferation and availability of inexpensive high-power commercial RF sources has made the EM spectrum crowded and contested, challenging our spectrum dominance. The numerous tactical advantages offered by operating at higher frequencies, most notably the wide bandwidths available, is driving both commercial and DoD solid-state and vacuum electronic amplifiers into the millimeter wave (mm-wave) spectrum above 30 GHz. Control of the mm-wave spectrum necessitates advanced and increasingly more sophisticated electronic components and systems. The performance of these systems strongly depends on the available amplifier power which impacts how much power the system can radiate. The High power Amplifier using Vacuum electronics for Overmatch Capability (HAVOC) program seeks to strengthen our dominance of the EM spectrum and create overmatch capability by developing a new class of wideband, high-power vacuum electronic amplifiers. The size, weight, and power (SWaP) will be consistent with reusable airborne and mobile platforms enabling an increased offset range and the ability to engage multiple targets at the speed of light. Realization of wideband, high power vacuum electronic amplifier technology will require significant advancements in cathodes with high current-density and long lifetime, beam-wave interaction circuits with wide bandwidth and high power handling capability, wideband and low-loss vacuum windows, and compact magnetic structures for electron beam transport. The HAVOC amplifier will provide leap-ahead capabilities to air, ground, and ship-based communications, sensing, and electronic warfare systems. Opportunities for transfer of the HAVOC technology to the Services will be identified during the execution of the early phases of the program. The technology transfer efforts will follow a spiral development process to mitigate risk and provide the opportunity to incorporate new technological developments as they occur. Basic research for this program is funded within PE 0601101E, Project ES-01. FY 2016 Plans: - Initiate the design and modeling of a wide-bandwidth, high power mm-wave vacuum electronic amplifier. - Identify performance parameters and engineering tradeoffs required to meet or exceed the program metrics for both power and bandwidth in a compact form factor, incorporating new concepts for novel beam-wave interaction structures and advanced thermal management.		-	12.000	18.000

UNCLASSIFIED

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Assess state of the art in cathodes, vacuum windows, and magnetic structures for electron beam transport and identify components and technologies that meet or exceed design requirements. FY 2017 Plans: - Design, fabricate, and test high current-density cathodes capable of producing beam current consistent with amplifier output power requirements. - Design, fabricate, and test wide bandwidth interaction structures with high beam-wave interaction efficiency and high power handling capability. - Design, fabricate, and test wide bandwidth vacuum windows with high power handling capability. - Investigate new magnetic materials and magnet configurations that enable compact, integrated beam focusing and transport architectures. - Integrate components into prototype amplifiers and begin testing.				
Title: Precise Robust Inertial Guidance for Munitions (PRIGM) Description: The DoD relies on GPS for ubiquitous and accurate positioning, navigation, and timing (PNT). With the increased prevalence of intentional GPS jamming, spoofing, and other GPS-denial threats, GPS access is increasingly unavailable in contested theaters and alternative sources of PNT are required. In particular, guided munitions navigation is the most immediate and among the most demanding of GPS-denial challenges, due to the necessity of operating in highly contested theaters and the stringent requirements for minimization of cost, size, weight, and power consumption (CSWaP). The Precise Robust Inertial Guidance for Munitions (PRIGM) program will develop low-CSWaP inertial sensor technology for GPS-free munitions navigation. PRIGM comprises two focus areas: 1) Development of a Navigation-Grade Inertial Measurement Unit (NGIMU) that transitions state-of-the-art MEMS to DoD platforms by 2020; and 2) Research and development of Advanced Inertial MEMS Sensors (AIMS) to achieve gun-hard, high-bandwidth, high dynamic range navigation requirements with the objective of complete autonomy in 2030. PRIGM will advance state-of-the-art MEMS gyros from TRL-3 devices to a TRL-6 transition platform (complete IMU) that enables Service Labs to perform TRL-7 field demonstrations. PRIGM will exploit recent advances in heterogeneous integration of photonics and CMOS and advanced MEMS technology to realize novel inertial sensors for application in extreme dynamic environments and beyond navigation-grade performance. Future warfighting scenarios will take place in a GPS-denied world. High-dynamics navigation applications, such as smart munitions, require low-CSWaP inertial sensors demonstrating high bandwidth, high precision, and high shock tolerance. Conventional MEMS inertial sensors rely on capacitive sensing to measure position, which suffer from perturbations due to asymmetry, temperature sensitivity, parasitic capacitances, and squeeze film damping of gas in narrow gaps. Various methods have been proposed to overcome challenges with capacitive readout. One solution is optical sensing, which has demonstrated high sensitivity, low noise position sensing and potential to reject external vibrations. Recent advances in heterogeneous		-	10.000	21.911

UNCLASSIFIED

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
integration, on-chip optical waveguides, and quantum-assisted sensing and readout of MEMS/NEMS have resulted in new capabilities to enable candidate technologies for PRIGM. The candidate technologies include optically interrogated MEMS gyroscopes and accelerometers, waveguide optical gyroscopes, and rate-integrating MEMS gyroscopes. Basic research for this program is funded within PE 0601101E, Project ES-01 and advanced development for the program is budgeted in PE 0603739E, Project MT-15. FY 2016 Plans: - Model and design architectures for chip-scale, waveguide optical gyroscopes, which combine the essential components and functionality of ring-laser into a photonic integrated circuit. - Model and design optically interrogated MEMS inertial sensors, leveraging the high sensitivity of optical interrogation with the precision machining and low-CSWaP enabled by MEMS. - Develop processes for co-fabrication of MEMS and photonic integrated circuits. - Design and simulate photonic and MEMS-photonic sensors suitable for high shock survival. FY 2017 Plans: - Integrate component technology and demonstrate integrated photonic-MEMS inertial sensors with beyond navigation grade performance. - Design and fabricate heterogeneously integrated, chip-scale waveguide optical gyroscopes. - Demonstrate navigation grade accuracy and stability of integrated inertial sensors.				
Title: Near Zero Energy RF and Sensor Operations (N-ZERO) Description: The DoD has an unfilled need for a persistent, event driven sensing capability, where physical, electromagnetic and other sensors can be pre-placed and remain dormant until awoken by an external trigger or stimulus. State-of-the-art sensors use active electronics to monitor the environment for the external trigger. The power consumed by these electronic circuits limits the sensor lifetime to durations of weeks to months. The Near Zero Power RF and Sensor Operations (N-ZERO) program will extend the lifetime of remotely deployed sensors from months to years. N-ZERO will develop the underlying technologies and demonstrate the capability to continuously and passively monitor the environment and wake-up an electronic circuit upon detection of a specific signature or trigger. Thereafter, sensor lifetime will be limited only by processing and communications of confirmed events. The N-ZERO program will replace the power consuming electronic circuits used for processing and detection of information in current systems with passive or extremely low power devices. The N-ZERO program will develop RF communications and physical sensor systems that collect, process, and detect the presence of useful information, while rejecting spurious signals and noise, using the energy in the collected information to perform these functions. This will eliminate or significantly reduce the standby power consumption from the battery. By doing so, the N-ZERO program will provide the warfighter with wireless sensors		-	4.500	13.000

UNCLASSIFIED

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions) systems with drastically increased mission life. The basic research component of this program is budgeted under PE 0601101E, Project ES-01.		FY 2015	FY 2016	FY 2017
FY 2016 Plans: - Design and fabricate hardware components and microsystems for detecting RF signals with received power levels less than 1 nano-Watt while consuming less than 10 nW of power. - Design and fabricate hardware components and microsystems for detecting and discriminating the presence of a specific machine at a distance of 0.5 m while consuming less than 10 nW of power consumption. - Identify government application spaces and transition paths that will make use of N-ZERO detection and signal processing. FY 2017 Plans: - Evaluate the detection performance and power consumption of the RF and physical sensor microsystems. - Design, fabricate and evaluate microsystems enabling passive or near zero energy collection, processing and detection of RF communications and physical sensor signatures at reduced (10 fold) signal strength. - Identify and engage potential users in the National Security space to develop N-ZERO transition opportunities.				
Title: Wafer-scale Infrared Detectors (WIRED)* Description: *Formerly Microwaves and Magnetics (M&M) Leveraging investments in high-volume wafer scale processing has made digital imaging technologies ubiquitous, for example, making high resolution digital cameras common place in every cell phone. A smaller scale revolution is currently underway due to the development of long-wave infrared (LWIR) thermal imaging sensors. These sensors are also manufactured at the wafer scale, and they are becoming widely available due to the low cost relative to existing infrared (IR) imaging technologies. No similar technology exists in the tactically and strategically important short-wave and mid-wave IR (SWIR/MWIR) bands. The Wafer-scale Infrared Detectors (WIRED) program addresses these needs by developing high performance SWIR and MWIR Focal Plane Array (FPA) technologies that are manufactured at the wafer scale. These sensors will provide increased standoff distances to smaller Tier I and II class unmanned aerial vehicle platforms, low cost missiles, hand held weapon sights/handheld surveillance systems, helmet-mounted systems, and ground vehicle-mounted threat warning systems. The MWIR detector technologies developed under WIRED will provide, for the first time, MWIR FPAs that do not require heavy, expensive cryogenic coolers. The SWIR detector technologies will provide, for the first time, diffraction limited imaging with compact optics. Significant challenges include obtaining high detector performance from disordered materials that can be deposited directly onto readout integrated circuits (ROICs). New ROIC designs will also be required to achieve the noise reduction and pixel pitches required for the suggested applications.		-	6.000	13.500

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
<i>FY 2016 Plans:</i> - Explore fundamental properties of disordered materials, and evaluate the processes that affect sensor performance at elevated operating temperatures. - Develop and evaluate MWIR sensor technology that is compatible with wafer-scale processing, and demonstrates high performance at operating temperatures compatible with low-cost thermoelectric coolers. - Develop and evaluate SWIR sensor technology that is compatible with wafer-scale processing, and provides an architecture which will scale to a near diffraction-limited pixel pitch. <i>FY 2017 Plans:</i> - Develop models that describe the fundamental behavior of disordered materials and apply them to device-level simulations. - Demonstrate imaging from MWIR detectors that are integrated directly onto ROICs and evaluate detector performance/ characteristics at temperatures of 230 K. - Demonstrate imaging from small pixel SWIR detectors that are integrated directly onto ROICs and evaluate detector performance/ characteristics.				
<i>Title:</i> Modular Optical Aperture Building Blocks (MOABB)* <i>Description:</i> *Formerly MultiPLEX While radio-enabled technologies manipulate radio waves for sensing (e.g. RADAR) and communication, optical systems leverage visible light and can enable foliage-penetrating light detection and ranging (LIDAR), navigation, 3D imaging, and long-range communications. Although the basic technology already exists, optical systems have been limited by their size, weight, and cost. A traditional optical telescope, for instance, requires expensive precision lenses and mirrors, large empty volumes for gathering and focusing light, and heavy mechanical steering components. Mechanical steering's limited speed and precision also impedes the use of optical systems in certain defense applications, although LIDAR is more suitable for detailed imaging relative to RADAR. The Modular Optical Aperture Building Blocks (MOABB) program seeks to greatly reduce the size and weight of optical systems while increasing steering rates. Specifically, MOABB aims to construct millimeter scale optical unit cells that can be coherently arrayed onto a flat surface to form a much larger, higher power device. These building blocks would replace the precision lenses, mirrors, and mechanical components from a conventional optical system. MOABB would also develop scalable optical phased arrays, borrowing from RADAR the technology required to steer electromagnetic waves, such as light and radio, without mechanical components. These advances would allow for a 100-fold reduction in size and weight and a 1,000-fold increase in steering rate. For applications such as LIDAR, laser communications and laser illumination, MOABB provides a compelling opportunity to replace empty space and bulk components with a planar, integrated system.		-	8.000	15.000

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
FY 2016 Plans: - Design and simulate non-mechanically steered millimeter-scale transmit and receive unit cells with 5mW of output power. - Perform preliminary thermal modeling of the device, demonstrating a path to air-cooling. FY 2017 Plans: - Complete architecture design and application study for chip-scale LIDAR. - Fabricate and test a millimeter-scale unit cell transmit and receive elements. - Simulate low-loss grating design.				
Title: Circuit Realization At Faster Timescales (CRAFT)* Description: *Formerly Diamond Enhanced Devices (DiamEnD) High performance electronics are at the heart of most modern military systems. Today, when selecting the electronics for advanced systems, DoD programs must choose between a high performing, custom integrated circuit that takes years to design, or a significantly lower performing general purpose integrated circuit that can be designed in a few months. The tradeoff between performance and time has placed the DoD in an undesirable state. The Circuit Realization At Faster Timescales (CRAFT) Program will break this paradigm by developing a custom integrated circuit design flow and methodology that will drastically reduce the amount of effort required to design a custom integrated circuit by 10 times while preserving high performance. CRAFT will enable critical DoD electronic system needs by reducing the barrier to the design and fabrication of custom integrated circuits in leading-edge CMOS technology. The CRAFT program will investigate novel design flows that utilize recent advances in software development methodology to reduce the amount of required design time. The goal will be a reduction in the manual labor required for verification by automating much of the design tasks with automated generators. In addition, CRAFT will explore increasing the level of design reuse and the flexibility of transferring a design from one foundry to another as well as migrating from one foundry technology to a more advanced technology.		-	9.000	21.000
FY 2016 Plans: - Complete design submissions for the first Fin Field Effect Transistor (FinFET) multi-project wafer shuttle run. - Define the initial architecture of the proposed object-oriented design flows. - Initiate effort to establish a repository where the Intellectual Property (IP), methodology, and tools required to implement the object oriented design flow will be stored and distributed. FY 2017 Plans: - Complete and evaluate the first two FinFET multi-project wafer shuttle runs.				

UNCLASSIFIED

Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Initiate efforts to transfer design elements between foundries and across technology nodes. - Complete initial testing of at least two full object oriented design flows.				
Title: Atomic Clock with Enhanced Stability (ACES)* Description: *Formerly Next Generation Atomic Clock Atomic clock technology provides the high-performance backbone of timing and synchronization for DoD navigation, communications, Intelligence Surveillance and Reconnaissance (ISR), and Electronic Warfare (EW) systems. Prior DARPA investment in Chip-Scale Atomic Clock (CSAC) technology has led to recent demonstrations of enhanced DoD capabilities, enabled by the availability of atomic-quality timing in portable battery-powered applications. The Atomic Clock with Enhanced Stability (ACES) program will develop a next-generation low-size, weight, and power (SWaP) atomic clock, with 100X-1000X improvement in key performance parameters, by employing alternative approaches to atomic confinement and interrogation, with particular focus on developing the component technologies necessary to enable low-cost manufacturing and robust deployment in harsh DoD environments. ACES will develop chip-scale atomic clocks achieving temperature coefficient of frequency < 10⁻¹⁵/°C, drift < 10⁻¹³/month, instability < 10⁻¹¹/sqrt(tau), and retrace < 10⁻¹³ which are robust against acceleration and magnetic fields (10⁻¹³/g and 10⁻¹³/gauss, respectively). This will enable precise timing on low size, weight, and power (SWaP) platforms with extended mission duration. In order to achieve these performance metrics, new enabling technology and interrogation techniques will be integrated into systems. FY 2016 Plans: - Begin modelling and simulation to support architecture development of the ACES device. FY 2017 Plans: - Perform Laboratory demonstration of functioning clock of the ACES architecture. - Develop and verify low-SWaP physics package components consistent with proposed performance and overall physics package power consumption of <250 mW. - Demonstrate a breadboard atomic clock physics package with power consumption < 250 mW, instability of less than 10⁻¹¹/sqrt(tau), and frequency retrace of less than 10⁻¹¹. - Develop and design an integrated physics package with overall volume of < 30cm³ and power consumption of <250 mW.		-	5.000	14.000
Title: Limits of Thermal Sensors (LOTS) Description: The long wave infrared (LWIR) is the most commonly used spectral band for thermal imagery, and current systems must choose between high performance cryogenically cooled focal plane arrays (FPAs), and uncooled microbolometers.		-	-	9.000

UNCLASSIFIED

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Microbolometers offer a significant reduction in size, weight, and cost (SWaP-C), at the expense of reduced sensitivity and slower response time. The objective of the LOTS program is to demonstrate a detector technology that breaks this traditional trade space by providing the same benefits in SWaP-C as current microbolometers while approaching the sensitivity of a cryogenically cooled sensor. The result will be the ability to deploy smaller, lighter, cheaper sensors on higher value assets and in more critical missions. FY 2017 Plans: - Demonstrate at least 3x performance improvement in uncooled microbolometers over current production performance. - Demonstrate sensor fabrication in a production environment.				
Title: Connect.Everything Description: The Connect.Everything program will focus on the fielding of low-power, intelligent communication modules with high functionality density to enable ubiquitous connectivity. Research efforts will focus on leveraging commercial industry investment in future wireless technology to develop communication modules that operate within the various unlicensed radio frequency (RF) and millimeter wave (mm-wave) frequency bands. Employing advanced silicon technology, a fully-integrated multi-channel transceiver array including antenna, RF front-end amplifiers, passives, modems, and digital processors will be realized with a goal of reducing the barrier of connecting an existing device into a high data rate network. These universal communication modules will be capable of accepting digital input data and DC power only, modulating the digital data and generating RF/mm-wave radio signals, and receiving and demodulating external RF/mm-wave radio signals into digital output data. More importantly, built-in calibration, tuning, and self-test functions will be integrated so that the communication module will not require costly post-manufacture testing and evaluation. The program will extend current state of art Multiple-Input Multiple-Output (MIMO) techniques toward future applications which require gigahertz bandwidth, low latency, low power, and high power efficiency to support seamless connectivity between users, sensors, payloads, and platforms across the RF and mm-wave spectrum. FY 2017 Plans: - Develop a design concept for a fully-integrated, multi-channel communication module with embedded radio circuitry and digital processing capability to enable digital-in-to-RF transmitters and RF-in-to-digital-out receivers on a single integrated circuit. - Design a subset of the critical RF/mm-wave and digital circuits that enhance the functionality of the communication module. - Evaluate the communication capabilities, limitations, power consumption, and output power as well as spectrum efficiency of the communications module using modeling and simulation tools.		-	-	9.000
Title: IntraChip Enhanced Cooling (ICECool)		18.000	4.750	-

UNCLASSIFIED

Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Description: The IntraChip Enhanced Cooling (ICECool) program is exploring disruptive technologies that will remove thermal barriers to the operation of military electronic systems, while significantly reducing size, weight, and power consumption. These thermal barriers will be removed by integrating thermal management into the chip, substrate, or package technology. Successful completion of this program will raise chip heat removal rates to above 1 kW/cm² and chip package heat removal density to above 1kW/cm³ in RF arrays and embedded computers. Specific areas of focus in this program include overcoming limiting evaporative and diffusive thermal transport mechanisms at the micro/nano scale to provide an order-of-magnitude increase in on-chip heat flux and heat removal density, determining the feasibility of exploiting these mechanisms for intrachip thermal management, characterizing the performance limits and physics-of-failure of high heat density, intrachip cooling technologies, and integrating chip-level thermal management techniques into prototype high power electronics in RF arrays and embedded computing systems. FY 2015 Accomplishments: - Demonstrated the full implementation of the fundamental building blocks of evaporative intrachip cooling including embedded micron-scale microfluidic channels with pin fins in 3D Silicon (Si) chips with two-phase flow approaching 90% vapor exit quality. - Demonstrated High Power Amplifiers (HPA) thermal test vehicles with thermal resistance reduced by 3x compared to the State of the Art (SoA) that successfully handled die-level heat fluxes of 1 kW/cm² and transistor hot spots fluxes of 30 kW/cm² as well as embedded High Performance Computers (HPC) thermal test vehicles that successfully handled hot spot fluxes of 2 kW/cm². - Designed application-oriented electrical test vehicles to demonstrate the performance benefits of embedded microfluidic cooling and related these results to system-level performance and size, weight, power and cost (SWaPC) benefits to DoD programs-of-record through the use of intrachip thermal management technologies. - Designed fully-functional HPAs and HPCs to demonstrate the thermal and electrical performance benefits of embedded microfluidic cooling where the reduction in thermal resistance will enable a 3x or greater increase in output power (HPAs) or computational performance (HPCs) compared to the State of the Art (SOA) baseline. FY 2016 Plans: - Perform reliability testing of ICECool electrical demonstration modules to establish mean time to failure and compatibility with relevant Military specifications. - Test and demonstrate fully-functional HPAs with a 3x or greater increase in output power over the baseline GaN-on-SiC approach. - Design application-ready ICECool modules and subarrays to facilitate transition of ICECool enabled components into relevant systems.				

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Engage in transition activities for the ICECool technology to include insertion of ICECool enabled components in relevant subsystems such as transmit/receive modules and embedded airborne computing platforms.				
Title: In vivo Nanoplatfroms (IVN) Description: The In vivo Nanoplatfroms (IVN) program seeks to develop the nanoscale systems necessary for in vivo sensing and physiologic monitoring and delivery vehicles for targeted biological therapeutics against chemical and biological (chem-bio) threat agents. The nanoscale components to be developed will enable continuous in vivo monitoring of both small (e.g., glucose, nucleic acids, biomarkers) and large molecules (e.g., biological threat agents). A reprogrammable therapeutic platform that targets gene regulatory sequences will enable tailored therapeutic delivery to specific areas of the body (e.g., cells, tissue, compartments) in response to traditional, emergent, and engineered threats. The key challenges to developing these systems include safety, toxicity, biocompatibility, sensitivity, response, and targeted delivery. The IVN program will have diagnostic and therapeutic goals that enable a versatile, rapidly adaptable system to provide operational support to the warfighter in any location. FY 2015 Accomplishments: - Demonstrated broad capability of in vivo nanoplatfrom sensors to detect additional military-relevant analytes (e.g., pH, cortisol) in an animal model with a robust signal. - Demonstrated broad capability of in vivo nanoplatfrom therapeutics targeting gene regulatory sequences to maintain force health and reduce additional military-relevant pathogens or disease cofactors (e.g., multi-drug resistant bacteria, neurological disease) in an animal model. - Updated regulatory approval pathway with results from animal model safety and efficacy testing. FY 2016 Plans: - Demonstrate enhanced therapeutic performance via molecular targeting approaches in an animal model. - Demonstrate the ability of skin-based sensors to detect physiologically relevant molecules (e.g., pH, ions, glucose, lactate, and cortisol) in an animal model. - Demonstrate the ability of an in vivo nanoplatfrom to protect against infectious disease in an animal model. - Continue to update regulatory approval pathway with results from animal model safety and efficacy testing.		14.500	9.765	-
Title: Pixel Network (PIXNET) for Dynamic Visualization Description: The PIXNET program addresses the squad level capability gap for target detection, recognition and identification in day/night missions through real-time fusion of visible and thermal infrared (IR) imagery. The vision of the program is to offer the warfighter a small and versatile camera that would be affordable for individual soldiers and provide multiple band imagery with fusion capability to take full advantage of different wavelength-band phenomenology in a compact single unit. In the future, the availability of the PIXNET camera would enable a peer-to-peer networked system for image sharing within a squad, thereby providing a better common operating picture of the battlefield and significantly enhancing the warfighter's situational		13.000	9.500	-

UNCLASSIFIED

Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
understanding. The program aims to develop a low size, weight and power (SWaP), low cost, soldier-portable multiband infrared camera that will provide real-time single and multiple band imagery using a combination of a thermal and reflected spectral band. The use of fused imagery in the PIXNET design will allow the soldier to detect camouflaged targets and distinguish targets from decoys. The PIXNET camera will eliminate limitations posed by current camera systems, allowing for the detection, recognition and identification of targets from a single camera in daylight or no-light conditions. The PIXNET program will focus on a significant reduction in SWaP and cost of infrared sensor components to enable the deployment of this technology to a wide range of participants in the theater. The emphasis on a small form factor will enable new opportunities such as surveillance with small Unmanned Aerial Vehicles (UAV), multi-band rifle sights, vehicle-mounted systems, as well as helmet-mounted and handheld surveillance systems. The phenomenology of utilizing the unique characteristics of different infrared wavelengths for target detection will be exploited. The combination of a smart phone and PIXNET camera at the soldier level will enable more effective tactics, techniques and procedures (TTP) over the current capability. The PIXNET program takes advantage of the computing capability of smart phones to process and fuse multicolor images and send them as videos or still images to the warfighter's helmet-mounted display via a wireless or wired connection. FY 2015 Accomplishments: - Demonstrated brass board components for the visible and near infrared/long-wave infrared (VNIR/LWIR) helmet mounted camera. - Refined algorithms to fuse data from thermal and reflective bands with good image registration. - Completed data fusion demonstration and preliminary imaging for short-wave infrared/long-wave infrared (SWIR/LWIR) helmet mounted camera. - Completed prototype design for short-wave infrared/mid-wave infrared (SWIR/MWIR) clip-on weapon sight camera. - Achieved 99.8% operability with MWIR Focal Plane Array (FPA) base layer of the clip-on weapon sight camera. FY 2016 Plans: - Demonstrate the VNIR/LWIR camera and program completion. - Demonstrate the SWIR/LWIR helmet mounted camera on smart phone with real-time, on-board multi-band fusion and program completion. - Demonstrate bench-scale brassboard SWIR/MWIR camera with image fusion algorithms on an external laptop to demonstrate functionality. - Demonstrate final SWIR/MWIR clip-on weapon sight with on-board fusion and wireless transmission to a smart phone and program completion.				
Title: Vanishing Programmable Resources (VAPR)		5.500	9.000	9.000

UNCLASSIFIED

Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Description: The Vanishing Programmable Resources (VAPR) program will create microelectronic and mechanical systems capable of physically disappearing (either in whole or in part) in a controlled, triggerable manner, a characteristic referred to as transience. The program will develop and establish an initial set of materials and components along with integration and manufacturing capabilities to undergird a fundamentally new class of electronics and mechanical structures defined by their performance and transience. These transient electronics and structural systems ideally should perform in a manner comparable to Commercial Off-The-Shelf (COTS) systems, but with limited device persistence that can be programmed, adjusted in real-time, triggered, and/or be sensitive to the deployment environment. Applications include sensors for conventional indoor/outdoor environments (buildings, transportation, and materiel), environmental monitoring over large areas, simplified diagnosis, treatment, and health monitoring in the field and airborne delivery vehicles with vanishing properties. VAPR will explore transience characteristics of electronic devices and structural materials as well as build out an initial capability to make transient electronics and transient structural materials a deployable technology for the DoD and Nation. The technological capability developed through VAPR will be demonstrated through two final test vehicles. The transient electronics test vehicle will be a vanishing sensor with RF link. The sensor with RF link will serve as an application vehicle showing the manufacturability of the research and process developed in the VAPR program being performed in PE 0601101E, Project TRS-01. The sensor with RF link is meant to be functional on its own, but also a leading indicator of the types of circuits possible under the VAPR program. The transient structural materials demonstration will be a vanishing air delivery vehicle capable of precise, gentle drops of small payloads (~3 lbs.). This demonstration will be functional on its own and will also be a leading indicator of the types of complex vanishing mechanical structures enabled by VAPR materials and technologies. The resulting prototype designs will establish a fundamental capability to gently, precisely, and without debris deliver mission-critical payloads and are expected to broadly apply to various concepts of operation (CONOPS) relevant to national security. FY 2015 Accomplishments: - Achieved a transience time of less than or equal to 5 minutes for simple electronic devices. - Reduced the variability of transience time to less than or equal to 90 seconds for simple electronic devices. - Demonstrated capability to operate foundry-fabricated transient electronic circuits and subsequent controlled transience. FY 2016 Plans: - Complete integration of transient devices and materials to form fully functional microsystems. - Achieve a transience time of less than or equal to 30 seconds for transient functional microsystems. - Improve the variability of transience time to less than or equal to 10 seconds. - Realize reliable operation of transient microsystems for greater than 100 hours after deployment, with subsequent controlled transience. FY 2017 Plans:				

UNCLASSIFIED

Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Optimize novel transient materials for application in the air delivery vehicle, since it must meet structural and processing requirements while guaranteeing full and complete transience. - Initiate commercial-scale production of novel transient materials. - Complete preliminary design reviews of air delivery system that meets program-defined air-release and landing specifications.				
Title: Hyper-wideband Enabled RF Messaging (HERMES) Description: Modern weapons systems are dependent on radio frequency (RF) links for communications, command and control, geolocation and battle management. This dependence will only grow with the move to disaggregated systems in the battlefield. To create assured RF links in contested environments, HERMES will study the architectures and develop the technologies to enable spread-spectrum links with 10 GHz of instantaneous bandwidth. The ultimate objective is >70 dB of jammer suppression. This program will explore the limits of jammer suppression through a combination of processing gain and tunable filtering in a hyper-wideband system. FY 2015 Accomplishments: - Performed analysis and simulation of frequency-dependent channel propagation effects with associated mitigation methods. - Defined system architecture to include wireless RF transmitter and receiver architectures. - Tested prototype communication link demonstrating 6 GHz of instantaneous bandwidth and 25dB of jammer suppression. FY 2016 Plans: - Develop and test photonic-enabled wideband receivers for future scaling of link technologies with overall reduction of the system size, weight and power (SWaP). - Demonstrate a prototype broadband wireless communication link with 10 GHz of instantaneous bandwidth and 70dB of jammer suppression.		2.000	3.000	-
Title: Direct SAMpling Digital ReceivER (DISARMER) Description: The goal of the Direct SAMpling Digital Receiver (DISARMER) program is to produce a hybrid photonic-electronic analog-to-digital converter (ADC) capable of coherently sampling the entire X-band (8-12 GigaHertz (GHz)). Conventional electronic wideband receivers are limited in dynamic range by both the electronic mixer and the back-end digitizers. By employing an ultra-stable optical clock, the DISARMER program will allow for mixer-less digitization and thereby improve the dynamic range 100x over the state of the art. Such a wide bandwidth, high fidelity receiver will have applications in electronic warfare and signals intelligence systems while dramatically reducing the cost, size and weight of these systems.		2.000	-	-

UNCLASSIFIED

Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions) The DISARMER program will develop a low jitter mode-locked laser to be used as the sampling source. The program will also develop a novel photonic architecture in a compact platform capable of hybrid electronic-photonic track-and-hold functionality and coherent photo-detection. This program has advanced technology development efforts funded in PE 0603739E, Project MT-15. FY 2015 Accomplishments: - Demonstrated 5 femtosecond (fs) optical clock jitter in a compact mode-locked source. - Fabricated and tested the building block optical circuits for coherent demodulation of the optical signal. - Finalize fabrication and packaging of temperature stable laser module capable of 8 GHz repetition rate, 1 ps pulse width, and < 5 fs of integrated timing jitter. - Finalize fabrication and integration of photonic de-modulation module with high power photodiodes.		FY 2015	FY 2016	FY 2017
Title: Micro-Technology for Positioning, Navigation, and Timing (Micro PN&T) Description: The Micro-Technology for Positioning, Navigation, and Timing (Micro-PNT) program developed low-Cost, Size, Weight, and Power (CSWaP) inertial sensors and timing sources for navigation in GPS degraded environments, primarily focusing on the development of miniature solid state and atomic gyroscopes and clocks. Both classes of sensors are currently unsuitable for small platform or dismount soldier applications. Micro Electro-Mechanical Systems (MEMS) sensors have limited performance but excellent CSWaP, while atomic sensors are capable of excellent performance but are limited to laboratory experiments due to complexity and high CSWaP. Micro-PNT advanced both technology approaches by improving the performance of MEMS inertial sensors and by miniaturizing atomic devices. Ultimately, low-CSWaP inertial sensors and clocks will enable ubiquitous guidance and navigation on all platforms, including guided munitions, unmanned aerial vehicles (micro-UAVs), and mounted and dismounted soldiers. The successful realization of Micro-PNT depends on development of new microfabrication processes and novel material systems for fundamentally different sensing modalities, as well as understanding the error sources at the microscale and the scaling relationships for size reduction of sensors based on atomic physics techniques. The Micro-PNT program included research into novel techniques for fabrication and integration of three-dimensional MEMS devices as well as theoretical and experimental studies of new architectures and geometries for MEMS inertial sensing. Atomic physics research included the development of new architectures for atomic inertial sensing and investigation of miniature enabling technologies, whose conventional counterparts are currently large, power hungry, and temperature sensitive, limiting high performance sensors to laboratory demonstrations. Advanced research for the program is budgeted in PE 0603739E, Project MT-12. FY 2015 Accomplishments: - Demonstrated on-chip MEMS calibration stages to track gyro bias and scale factor stability. - Demonstrated proof of concept sourcing and sinking of Rb for alkali vapor pressure control.		13.500	-	-

UNCLASSIFIED

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Demonstrated ultra-narrow linewidth lasers. - Demonstrated waveguide modulation of on-chip lasers at atomic resonance wavelengths. - Demonstrated self-calibrating MEMS gyroscope with long-term scale factor and bias of < 10 parts per million (ppm) of full scale range.				
Title: Terahertz Electronics Description: The Terahertz Electronics program developed the critical semiconductor device and integration technologies necessary to realize compact, high-performance microelectronic devices and circuits that operate at center frequencies exceeding 1 Terahertz (THz). There are numerous benefits for electronics operating in the THz regime and new applications in imaging, radar, communications, and spectroscopy. The Terahertz Electronics program was divided into two major technical activities: Terahertz Transistor Electronics that included the development and demonstration of materials and processing technologies for solid-state transistors and integrated circuits for receivers and exciters that operate at THz frequencies; and Terahertz High Power Amplifier Modules that included the development and demonstration of vacuum electronic traveling wave tube (TWT) amplifiers for high power amplification of THz signals. FY 2015 Accomplishments: - Completed measurements of receiver/exciter technologies at and above 0.67 THz. - Demonstrated oscillator circuits at 1.03 THz. - Demonstrated a prototype THz transceiver link using THz indium phosphide high electron mobility transistor (HEMT) technology. - Demonstrated a 1.03 THz solid-state amplifier, the first time a solid state circuit has operationally crossed the THz barrier. - Demonstrated improved thermal performance of vacuum amplifier for high duty cycle operation at THz frequencies. - Demonstrated the first vacuum electronic traveling wave tube amplifier at 1 THz.		8.020	-	-
Title: Nitride Electronic NeXt-Generation Technology (NEXT) Description: To realize high performance analog, Radio Frequency (RF) and mixed-signal electronics, a next-generation transistor technology with high cutoff frequency and high breakdown voltage is under development. This technology enabled large voltage swing circuits for military applications that the current state-of-the-art silicon transistor technology cannot support. The objective of the NEXT program was to develop a revolutionary, wide band gap, nitride transistor technology that simultaneously provides extremely high-speed and high-voltage swing [Johnson Figure of Merit (JFoM) larger than 5 Terahertz (THz)-V] in a process consistent with large scale integration of enhancement/depletion (E/D) mode logic circuits of 1,000 or more transistors. In addition, this fabrication process was reproducible, high-yield, high-uniformity, and highly reliable. The accomplishment of this goal was validated through the demonstration of specific program Process Control Monitor (PCM) Test Circuits such as 5, 51 and 501-stage ring oscillators in each program phase. The impact of this next-generation nitride electronic		4.280	-	-

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
technology is the speed, linearity, and power efficiency improvement of RF and mixed-signal electronic circuits used in military communications, electronic warfare and sensing.				
FY 2015 Accomplishments: - Established the baseline of the high-speed / high breakdown voltage NEXT fabrication technology with high reproducibility and yield. - Designed, fabricated, and tested military-relevant circuits, such as millimeter-wave low noise amplifiers, power amplifiers and triplers, using the developed NEXT transistor technology. - Developed NEXT process design kit to allow circuit designers to utilize NEXT technology in other advanced circuit designs.				
Title: Microscale Plasma Devices (MPD) Description: The goal of the Microscale Plasma Devices (MPD) program was to design, develop, and characterize MPD technologies, circuits, and substrates. The MPD program focused on development of fast, small, reliable, high-carrier-density, micro-plasma switches capable of operating in extreme conditions, such as high-radiation and high-temperature environments. Specific focus was given to methods that provide efficient generation of ions that can perform robust signal processing of radio frequency (RF) through light electromagnetic energy over a range of gas pressures. Applications for such devices are far reaching, including the construction of complete high-frequency plasma-based circuits, and microsystems with superior resistance to radiation and extreme temperature environments. Two and multi-terminal devices consisting of various architectures were developed and optimized under the scope of this program. MPDs were developed in various circuits and substrates to demonstrate the efficacy of different approaches. MPD-based microsystems were demonstrated in DoD applications where electronic systems must survive in extreme environments. The MPD applied research program focused on transferring the fundamental scientific advances funded by PE 0601101E, Project ES-01 to produce complex circuit designs that may be integrated with commercial electronic devices. The MPD program resulted in the design and modeling tools, as well as the fabrication capabilities necessary to commercially manufacture high-performance microscale-plasma-device-based electronic systems for advanced DoD applications. FY 2015 Accomplishments: - Completed integration of the simulation efforts into the Modeling, Simulation and Design Tool (MSDT) for commercial development of microplasma based electronics. - Completed final testing of microcavity materials for robustness in a high power electromagnetic application in order to demonstrate a Technology Readiness Level (TRL) as needed for technology transition.		2.000	-	-

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 2: Applied Research</i>		R-1 Program Element (Number/Name) PE 0602716E / <i>ELECTRONICS TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Completed demonstration of plasma-based materials and devices in representative system applications for transition to multiple DoD customers.				
Accomplishments/Planned Programs Subtotals		169.690	174.798	221.911
D. Other Program Funding Summary (\$ in Millions) N/A				
Remarks				
E. Acquisition Strategy N/A				
F. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.				

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>					R-1 Program Element (Number/Name) PE 0603286E / <i>ADVANCED AEROSPACE SYSTEMS</i>							
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	123.292	173.631	182.327	-	182.327	156.089	169.521	184.156	189.156	-	-
AIR-01: <i>ADVANCED AEROSPACE SYSTEMS</i>	-	123.292	173.631	182.327	-	182.327	156.089	169.521	184.156	189.156	-	-

A. Mission Description and Budget Item Justification

The Advanced Aerospace Systems program element is budgeted in the Advanced Technology Budget Activity because it addresses high pay-off opportunities to dramatically reduce costs associated with advanced aeronautical systems and provide revolutionary new system capabilities for satisfying current and projected military mission requirements. Research and development of integrated system concepts, as well as enabling vehicle subsystems will be conducted. Studies conducted under this project include examination and evaluation of emerging aerospace threats, technologies, concepts, and applications for missiles, munitions, and vehicle systems.

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	129.723	185.043	193.011	-	193.011
Current President's Budget	123.292	173.631	182.327	-	182.327
Total Adjustments	-6.431	-11.412	-10.684	-	-10.684
• Congressional General Reductions	0.000	-1.394			
• Congressional Directed Reductions	0.000	-10.018			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	-2.480	0.000			
• SBIR/STTR Transfer	-3.951	0.000			
• TotalOtherAdjustments	-	-	-10.684	-	-10.684

Change Summary Explanation

FY 2015: Decrease reflects reprogrammings and the SBIR/STTR transfer.

FY 2016: Decrease reflects congressional reduction and for Section 8024, FFRDC.

FY 2017: Decrease reflects completion of several Tactically Exploited Reconnaissance Node (TERN) program milestones.

C. Accomplishments/Planned Programs (\$ in Millions)	FY 2015	FY 2016	FY 2017
Title: Tactically Exploited Reconnaissance Node (TERN)	44.558	32.000	12.000
Description: The goal of the Tactically Exploited Reconnaissance Node (TERN) program, a joint effort with the Office of Naval Research, is to develop a systems approach for, and perform technical demonstration of, a Medium-Altitude, Long-Endurance			

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603286E / <i>ADVANCED AEROSPACE SYSTEMS</i>		
C. Accomplishments/Planned Programs (\$ in Millions) Unmanned Aerial Vehicle (MALE UAV) capability from smaller ships. The program will demonstrate the technology for launch and recovery of large unmanned aircraft capable of providing persistent 24/7 Intelligence, Surveillance, and Reconnaissance (ISR) and strike capabilities at long radius orbits. By extending the ISR/strike radius and simultaneously increasing time on station beyond current capabilities from smaller ships, TERN will enable novel operational concepts including maritime surveillance and responsive, persistent deep overland ISR and strike, without requirement for forward basing. To achieve these goals, the program will create new concepts for aircraft launch and recovery, aircraft logistics and maintenance, and aircraft flight in regimes associated with maritime operating conditions. The program will culminate in a launch and recovery demonstration. Application of TERN technologies and operational concepts will enable a novel and cost efficient approach for multiple mission sets. The transition partner is the Navy.		FY 2015	FY 2016	FY 2017
FY 2015 Accomplishments: - Continued technology maturation and completion of preliminary design. - Continued integrated aircraft risk reduction simulation and testing. - Initiated subscale bench testing of propulsion system. - Commenced integrated ship-aircraft simulation activity. - Initiated software in the loop / hardware in the loop design. - Conducted large-scale demonstration of select technology development elements.				
FY 2016 Plans: - Complete high fidelity integrated ship-aircraft simulation. - Commence procurement of long-lead demonstrator system components. - Complete detailed design of demonstrator aircraft. - Begin fabrication and testing of demonstrator system hardware. - Initiate software in the loop / hardware in the loop build. - Complete integrated testing of propulsion subsystem. - Initial testing of ship relative navigation system. - Perform subsystem risk reduction demonstrations.				
FY 2017 Plans: - Conduct demonstrator system Critical Design Review (CDR). - Commence demonstrator system wing and fuselage fabrication. - Perform demonstrator system integrated avionics testing. - Conduct integrated propulsion system testing. - Complete vehicle structure tooling. - Conduct vehicle structure assembly and testing.				

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603286E / <i>ADVANCED AEROSPACE SYSTEMS</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Conduct demonstrator system assembly ground checkout.				
Title: Collaborative Operations in Denied Environment (CODE) Description: The goal of the Collaborative Operations in Denied Environment (CODE) program is to enhance mission performance, reduce cost, confound adversaries, and reduce reliance on space assets for navigation and communication by distributing mission functions such as sensing, communication, precision navigation, kinetic, and non-kinetic effects to small platforms and increasing their level of autonomy. Collaboration of multiple assets offers new possibilities to conduct military missions using smaller air platforms to enhance survivability, reduce overall acquisition cost, create new effects, increase communications range and robustness in denied environments, increase search area, increase areas held at risk, reduce target prosecution reaction time, and provide multi-mission capabilities by combinations of assets. This effort will specifically focus on developing and demonstrating approaches that will expand the mission capabilities of legacy air assets through autonomy and collaborative behaviors, within a standard based open architecture. Potential transition partners include the Air Force, Army, and Navy. FY 2015 Accomplishments: - Performed trade studies and decomposed selected missions. - Developed collaborative algorithms, autonomous tactics, concepts for communication, and supervisory interface. - Developed software module specifications compliant with standard based open architecture including OSD unmanned aircraft system control segment and other standards when applicable. - Evaluated algorithms, tactics, communication and interfaces, in high fidelity faster-than-real time simulation against key performance objectives. FY 2016 Plans: - Implement algorithms in first release of flightworthy software (release 1) hosted in mission computer compatible with demonstration platform and objective operational platforms. - Modify demonstration platform to include mission computer and mesh network capable radio. - Demonstrate in-flight capabilities of release 1 focused on basic software functionality verification, initial autonomy modules including formation flight, GPS denied navigation, and other vehicle level autonomy modules such as on-board real time sensor processing, contingency management, and mission planning. - Demonstrate release 1 collaboration algorithms in real time simulation, including low bandwidth sensor fusion and collaborative tasking that maximizes system effectiveness. - Develop collaborative algorithms, tactics, concepts for communication, and human interface. - Evaluate algorithms, tactics, communication and interfaces, in non-real time simulation. FY 2017 Plans:		19.000	28.543	29.027

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C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Continue development of collaborative algorithms. - Select algorithms for the current leading capabilities: collaborative navigation without GPS, formation flight, simultaneous time of arrival from multiple azimuth against moving targets, dynamic prioritized target re-assignment to compensate for attrition, synchronized search using multiple sensor types, collaborative communication using relays or other techniques, closed loop tracking and identification, and terse communication protocols for data fusion and task allocation. - Continue software maturation through progressive software releases. - Validate software in hardware in the loop testing that includes mesh network, mission computer, mission sensors, and high fidelity air vehicle simulator. - Validate major software release 2 and 3 in flight with increasing number of real and virtual unmanned airplanes. - Collaborate with operational system owners and other partners to develop early transition opportunities.				
Title: Hypersonic Air-breathing Weapon Concept (HAWC) Description: The Hypersonic Air-breathing Weapon Concept (HAWC) program is a Joint DARPA / Air Force effort that will develop and demonstrate technologies to enable transformational changes in responsive, long-range strike against time-critical or heavily defended targets. HAWC will pursue flight demonstration of the critical technologies for an effective and affordable air-launched hypersonic cruise missile. These technologies include advanced air vehicle configurations capable of efficient hypersonic flight, hydrocarbon scramjet-powered propulsion to enable sustained hypersonic cruise, thermal management approaches designed for high-temperature cruise, and affordable system designs and manufacturing approaches. HAWC technologies also extend to reusable hypersonic air platforms for applications such as global presence and space lift. The HAWC program will leverage advances made by the previously funded Falcon, X-51, and HyFly programs. This is a joint program with the Air Force, and HAWC technologies are planned for transition to the Air Force after flight testing is complete. FY 2015 Accomplishments: - Continued risk reduction testing of subsystem technologies for hypersonic air-breathing missile demonstrator. - Completed technology demonstration system requirements review and began preliminary design of hypersonic air-breathing missile flight demonstration system. - Initiated full-scale freejet propulsion system design and fabrication. - Initiated detailed plans for flight testing of the air-breathing missile demonstration system. FY 2016 Plans: - Complete preliminary design of hypersonic air-breathing missile flight demonstration system. - Complete full-scale freejet propulsion system testing. - Begin fabrication and testing of thermal protection system materials. - Begin detailed design of the hypersonic air-breathing missile flight demonstration system. - Begin creating test-validated performance databases to anchor demonstration vehicle design.		5.500	13.500	49.500

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603286E / <i>ADVANCED AEROSPACE SYSTEMS</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Continue detailed plans for flight testing of the air-breathing missile demonstration system. FY 2017 Plans: - Continue updating test-validated performance databases to anchor demonstration vehicle design. - Complete critical design of hypersonic air-breathing missile flight demonstration system. - Conduct preliminary traceability assessment between the HAWC demonstration system and the HAWC operational system. - Complete software architecture and algorithm design. - Begin software-in-the-loop testing for the demonstration vehicle. - Begin procurement of long lead hardware for hypersonic air-breathing missile flight demonstration vehicle. - Initiate flight certification reviews with the test range. - Begin hardware-in-the-loop testing for the flight demonstration vehicle. - Initiate full-scale flight-like freejet engine testing. - Continue detailed plans for flight testing of the air-breathing missile demonstration system.				
Title: Tactical Boost Glide Description: The Tactical Boost Glide (TBG) program is a Joint DARPA / Air Force effort that will develop and demonstrate technologies to enable air-launched tactical range hypersonic boost glide systems, including flight demonstration of a vehicle that is traceable to an operationally relevant weapon that can be launched from current platforms. The program will also consider traceability to, and ideally compatibility, with the Navy Vertical Launch System (VLS). The metrics associated with this objective include total range, time of flight, payload, accuracy, and impact velocity. The program will address the system and technology issues required to enable development of a hypersonic boost glide system considering (1) vehicle concepts possessing the required aerodynamic and aero-thermal performance, controllability and robustness for a wide operational envelope, (2) the system attributes and subsystems required to be effective in relevant operational environments, and (3) approaches to reducing cost and improving affordability for both the demonstration system and future operational systems. TBG capabilities are planned for transition to the Air Force and the Navy. FY 2015 Accomplishments: - Completed TBG Concept of Operations (ConOps), Operational System conceptual design reviews and system capability documentation. - Completed TBG Demonstration System conceptual design and systems requirements reviews. - Completed initial Technology Maturation Plans (TMPs). - Completed initial Risk Management Plans (RMP). - Conducted initial test range and range safety coordination. - Began Phase I aerodynamic and aerothermal concept testing. - Began development of first generation aero databases.		15.100	11.200	22.800

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603286E / <i>ADVANCED AEROSPACE SYSTEMS</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Completed aerodynamic and aerothermal Government Reference Vehicle (GRV) risk reduction testing. - Completed booster range and energy management study. - Selected booster and launch platforms. FY 2016 Plans: - Complete operational analysis of the performer TBG operational systems. - Complete operational analysis of evolved Government Reference Vehicle (GRV). - Select TBG demonstration test range. - Complete Phase I aerodynamic and aerothermal concept testing. - Complete first generation aero databases. - Continue risk reduction testing. - Develop initial flight test plan. - Update TMPs and RMPs. - Complete Preliminary Design Reviews (PDR). - Complete initial range safety documentation. FY 2017 Plans: - Begin TBG concept refinement testing. - Continue risk reduction testing. - Complete second generation aero databases. - Complete Critical Design Review (CDR). - Begin procurement of hardware for demonstration vehicles. - Begin hardware in the loop (HWIL), software in the loop (SIL), and qualification testing. - Begin Assembly, Integration, and Test (AI&T). - Continue detailed flight test and range safety planning, coordination, and documentation.				
Title: Advanced Aerospace System Concepts Description: Studies conducted under this program examine and evaluate emerging aerospace technologies and system concepts for applicability to military use. This includes the degree and scope of potential impact/improvements to military operations, mission utility, and warfighter capability. Studies are also conducted to analyze emerging aerospace threats along with possible methods and technologies to counter them. The feasibility of achieving potential improvements, in terms of resources, schedule, and technological risk, is also evaluated. The results from these studies are used, in part, to formulate future programs or refocus ongoing work. Topics of consideration include: methods of defeating enemy anti-aircraft attacks; munition technologies to increase precision, range, endurance, and lethality of weapons for a variety of mission sets; novel launch systems; air vehicle control, power, propulsion, materials, and architectures; and payload and cargo handling systems.		6.360	6.000	3.000

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603286E / <i>ADVANCED AEROSPACE SYSTEMS</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
FY 2015 Accomplishments: - Completed hypersonic propulsion integration and flowpath assessments. - Performed study of rotating detonation engine operation with hydrocarbon fuels, including system design and operational concepts. - Initiated studies of emerging concepts. FY 2016 Plans: - Perform feasibility experiments of candidate technologies and system concepts. - Conduct trade studies and modeling and simulation for novel technologies. FY 2017 Plans: - Validate sub-system performance and conduct sub-system risk reduction testing. - Conduct enabling technology and sub-system feasibility experiments.				
Title: Technology for Enriching and Augmenting Manned - Unmanned Systems Description: The Technology for Enriching and Augmenting Manned - Aircraft (TEAM-US) project seeks to increase lethality, survivability, payload, and reach of combat aircraft by: (i) teaming them (wingmen) with advanced Unmanned Aerial Vehicles (UAVs), and (ii) enabling swarming employment and operations of manned and unmanned airborne systems. The synergy between the mission tailored UAV wingmen and the less survivable, but decision making manned platforms will provide access to contested airspace and enhance force projection. UAV wingmen will reduce air dominance lifecycle costs by dramatically reducing training costs. Legacy manned platforms will train with virtual unmanned teammates saving operations, maintenance, and logistics costs associated with manned wingmen. Unmanned wingmen can be developed for a wide variety of missions including penetrating intelligence, surveillance, and reconnaissance (ISR), electronic attack (EA), and weapons delivery. Mixed operations of manned and unmanned systems in a swarming configuration can be developed to support missions against networked-integrated air defenses and to support operations in highly contested environments. A common core will enable reduced development and integration costs. Finally, leveraging existing platforms for command, control, and battle management recapitalizes existing investments, making these 4th and 5th generation platforms viable participants in future anti-access, area denial scenarios where they may have limited survivability. Balancing in situ battle management with highly capable, mission specific unmanned teammates will offset new threat technologies, enabling more cost effective mission execution, and increasing the survivability of the manned platform team leader. The anticipated transition partners for this effort are the Air Force, Army, and Marine Corps. FY 2016 Plans: - Perform operational analysis and technology maturity assessments to determine the minimum set of critical platform attributes and technology advances required of an unmanned teammate.		-	9.588	-

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603286E / <i>ADVANCED AEROSPACE SYSTEMS</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Create a technology development and system attributes demonstration roadmap. - Develop and refine the final unmanned vehicle design and concept.				
Title: Vertical Take-Off and Landing (VTOL) Technology Demonstrator Description: The Vertical Take-Off and Landing (VTOL) Technology Demonstrator program will demonstrate revolutionary improvements in (heavier than air) VTOL air vehicle capabilities and efficiencies through the development of subsystem and component technologies, aircraft configurations and system integration. The program will build and flight test an unmanned 10,000 - 12,000 lb aircraft capable of sustained speeds in excess of 300 kt, demonstrate system level hover efficiency within 25 percent of the ideal power loading, and a lift-to-equivalent drag ratio no less than ten. Additionally, the demonstrator will be designed to have a useful load of no less than 40 percent of the gross weight with a payload capacity of at least 12.5 percent of the gross weight. A strong emphasis will be placed on the development of elegant, multi-functional subsystem technologies that demonstrate net improvements in aircraft efficiencies to enable new and vastly improved operational capabilities. Technologies developed under this program will be made available to all Services for application to future air systems development. This program is a continuation of applied research efforts funded in PE 0602702E, Project TT-07. The anticipated transition partners for this effort are the Army, Marine Corps, and Special Operations Forces. FY 2016 Plans: - Flight test and analyze data from a sub-scale vehicle demonstrator (~340 lb). - Continue preliminary design refinements leading toward detailed design of the demonstrator aircraft and associated subsystems. - Select performer for detailed design, fabrication, and flight test. - Complete preliminary design reviews of configuration and all subsystems. - Refine system design and initiate subsystem critical design reviews. - Initiate software design and flight control law development and simulation. - Develop detailed airworthiness and flight test preparation requirements in support of the full-scale technology demonstrator. - Perform subsystem testing necessary for subsystem design validation and critical design reviews. - Initiate aircraft assembly and manufacturing processes to include tooling design and fabrication. - Procure long-lead items for aircraft fabrication. FY 2017 Plans: - Complete detailed sub- and system-level validation and verification tests and analyses. - Perform hardware/software-in-the-loop testing. - Complete vehicle management system development and avionics requirements, as well as all elements of ground control and operator/pilot stations. - Complete flight test range selection and finalize flight test plans.		-	58.800	52.000

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603286E / <i>ADVANCED AEROSPACE SYSTEMS</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Complete test and evaluation of all elements and sub-systems of the aircraft. - Fabricate and assemble the full, complete aircraft with integrated systems and subsystems.				
Title: Distributed Fires (DFires) Description: The goal of the Distributed Fires (DFires) program is to create a capability which would allow for precision fires from extended ranges to be rapidly accessed for use. The DFires system would be a stand-alone system that would be transported by trucks, rotorcraft, or boats and delivered to supporting locations on the battlefield. The modular launcher unit would provide the communications link and pass along targeting commands to the onboard stores. The onboard stores would consist of multiple tube launched munitions. Technology areas to be developed include the overall system architecture, the communications requirements and protocols, and specific stores. The anticipated transition partners for this effort are the Army, Marine Corps, and Special Operations Forces. FY 2016 Plans: - Identify critical anti-access/area-denial theaters of operation. - Conduct trade space analysis and develop overall system architecture. - Assess target value, conduct preliminary design of multiple types of onboard stores. - Explore new technologies which could reduce vehicle size, enhance penetration capability (propulsion and avionics). FY 2017 Plans: - Conduct Systems Requirements Review (SRR). - Develop system concept of operations (CONOPS) and command and control (C2).		-	6.000	5.000
Title: Advanced Full Range Engine (AFRE) Description: The Advanced Full Range Engine (AFRE) program will establish the feasibility of hypersonic aircraft propulsion through a two-pronged approach. AFRE will demonstrate turbine to Dual Mode Ramjet (DMRJ) transition of a Turbine-Based Combined Cycle (TBCC) propulsion system utilizing an off-the-shelf turbine engine. Large scale components of this complex propulsion system will be developed and demonstrated independently, followed by a full-scale freejet TBCC propulsion system mode transition ground test. Accomplishing these objectives will enable future hypersonic systems resulting in transformational changes in long range strike, high speed Intelligence, Surveillance and Reconnaissance (ISR) and Two-Stage-To-Orbit (TSTO) operations. FY 2017 Plans: - Begin preliminary design of the TBCC transition demonstration propulsion system, and develop ground test and associated technology development plans. - Design, fabricate, and initiate large scale dual-inlet testing.		-	-	9.000

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603286E / <i>ADVANCED AEROSPACE SYSTEMS</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Design, fabricate, and initiate large-scale direct-connect combustor testing. - Initiate procurement of the turbine engine.				
Title: Aerial Reconfigurable Embedded System (ARES) Description: Current and future land and ship-to-shore operations will require rapid and distributed employment of U.S. forces on the battlefield. The Aerial Reconfigurable Embedded System (ARES) program developed a vertical take-off and landing (VTOL), modular unmanned air vehicle that can carry a 3,000 lb useful load at a range of 250 nautical miles on a single tank of fuel. ARES enabled distributed operations and access to compact, high altitude landing zones to reduce warfighter exposure to hostile threats and bypass ground obstructions. ARES modular capability allowed mission modules to be quickly interchanged and deployed at the company level. This enables the flexible employment of many different capabilities including: cargo resupply, casualty evacuation, reconnaissance, weapons platforms, and other types of operations. ARES vehicles could be dispatched to resupply isolated small units. ARES was suited for enhanced company operations concepts that would provide the warfighter/team increased situational awareness for operations in an urban environment. The enabling technologies of interest developed under the ARES program included vertical and translational flight, conversion between powered lift and wing borne lift, ducted fan propulsion systems, lightweight materials, tailless configuration, modularity, and advanced over-actuated flight controls for stable transition from vertical to horizontal flight. Additionally, the program explored opportunities for the design, development, and integration of new, key technologies and capabilities. These included adaptable landing gear concepts to enable operations from irregular landing zones and moving launch/recovery platforms, and autonomous take off and landing. The anticipated transition partners for this effort are the Army, Marine Corps, and Special Operations Forces. FY 2015 Accomplishments: - Completed assembly of drive train components for testing. - Completed assembly of airframe structure for load testing. - Completed proof load testing with flight hardware. - Completed review and revision of rotor control components. - Completed fabrication and assembly of revised rotor control components. - Completed drive train testing with flight components. - Completed development of flight control software to ensure successful flight and ground testing. - Conducted subsystem testing and integration of components into the full scale prototype ARES system. - Completed hardware-in-the-loop and software-in-the-loop testing with fully integrated full scale prototype ARES system. - Conducted ground demonstrations of the prototype vehicle in preparation for flight testing. FY 2016 Plans:		18.000	8.000	-

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603286E / <i>ADVANCED AEROSPACE SYSTEMS</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Conduct flight tests to demonstrate that the vehicle meets program objectives by flying with and without a cargo module to show cargo delivery, and validate flight envelope by expanding speed and altitude performance.				
Title: Persistent Close Air Support (PCAS) Description: The Persistent Close Air Support (PCAS) program significantly increased close air support (CAS) capabilities by developing a system to allow continuous CAS availability and lethality to the supported ground commander. The enabling technologies were: manned/unmanned attack platforms, next generation graphical user interfaces, data links, digital guidance and control, and advanced munitions. PCAS demonstrated the ability to digitally task a CAS platform from the ground to attack multiple/simultaneous targets. PCAS allowed the Joint Tactical Air Controller (JTAC) the ability to rapidly engage multiple moving targets simultaneously within the area of operation. PCAS's ability to digitally task a CAS platform to attack multiple/simultaneous targets would improve U.S. ground forces operations and speed of attack. The system was designed to reduce collateral damage and potential fratricide to friendly forces. Transition partners include the Air Force, Special Operations Command (SOCOM), and the United States Marine Corps (USMC). FY 2015 Accomplishments: - Completed flight testing and live fire demonstration of PCAS prototype system on both an A-10C and MV-22. - Transitioned elements of PCAS air and ground systems to USMC and SOCOM. - Prepared and commenced PCAS integration into the MQ-1C. - Conducted testing of the PCAS prototype system on MQ-1C hardware.		14.774	-	-
Accomplishments/Planned Programs Subtotals		123.292	173.631	182.327
D. Other Program Funding Summary (\$ in Millions) N/A				
Remarks				
E. Acquisition Strategy N/A				
F. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.				

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603286E / ADVANCED AEROSPACE SYSTEMS				Project (Number/Name) AIR-01 / ADVANCED AEROSPACE SYSTEMS					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Tactically Exploited Reconnaissance Node (TERN)	C/CPFF	AeroVironment, Inc. : CA	-	13.035	Oct 2014	0.000		0.000		-		0.000	Continuing	Continuing	Continuing
Tactically Exploited Reconnaissance Node (TERN)	C/CPFF	NorthropGrumman : CA	-	17.209	Oct 2014	27.370		9.540		-		9.540	Continuing	Continuing	Continuing
Tactically Exploited Reconnaissance Node (TERN)	C/Various	Various : Various	-	10.202		0.000		0.000		-		0.000	Continuing	Continuing	Continuing
Collaborative Operations in Denied Environment (CODE)	C/Various	Various : Various	-	16.033		4.514		0.000		-		0.000	Continuing	Continuing	Continuing
Collaborative Operations in Denied Environment (CODE)	C/TBD	TBD : TBD	-	0.000		19.960		22.915		-		22.915	Continuing	Continuing	Continuing
Hypersonic Air-breathing Weapon Concept (HAWC)	C/Various	Various : Various	-	2.651		0.000		0.000		-		0.000	Continuing	Continuing	Continuing
Hypersonic Air-breathing Weapon Concept (HAWC)	C/TBD	TBD : TBD	-	0.000		10.585		43.045		-		43.045	Continuing	Continuing	Continuing
Tactical Boost Glide	C/CPFF	LockheedMartin : CA	-	6.159	May 2015	0.000		0.000		-		0.000	Continuing	Continuing	Continuing
Tactical Boost Glide	C/Various	Various : Various	-	2.936		0.000		0.000		-		0.000	Continuing	Continuing	Continuing
Tactical Boost Glide	C/TBD	TBD : TBD	-	0.000		8.692		17.048		-		17.048	Continuing	Continuing	Continuing
Advanced Aerospace System Concepts	C/Various	Various : Various	-	5.788		5.460		2.730		-		2.730	Continuing	Continuing	Continuing
Technology for Enriching and Augmenting Manned - Unmanned Systems	C/TBD	Various : Various	-	0.000		7.920		0.000		-		0.000	0	7.920	0
Vertical Take-Off and Landing (VTOL) Technology Demonstrator	C/TBD	Various : Various	-	0.000		53.008		45.170		-		45.170	Continuing	Continuing	Continuing
Distributed Fires (DFires)	C/TBD	Various : Various	-	0.000		5.995		4.550		-		4.550	Continuing	Continuing	Continuing
Advanced Full Range Engine (AFRE)	C/TBD	Various : Various	-	0.000		0.000		8.190		-		8.190	Continuing	Continuing	Continuing

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603286E / ADVANCED AEROSPACE SYSTEMS				Project (Number/Name) AIR-01 / ADVANCED AEROSPACE SYSTEMS					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Aerial Reconfigurable Embedded System (ARES)	C/CPFF	Lockheed Martin : TX	-	7.277	Mar 2015	0.000		0.000		-		0.000	0	7.277	0
Aerial Reconfigurable Embedded System (ARES)	C/Various	Various : Various	-	8.599		5.550		0.000		-		0.000	0	14.149	0
Persistent Close Air Support (PCAS)	C/Various	Various : Various	-	13.272		0.000		0.000		-		0.000	0	13.272	0
Subtotal			-	103.161		149.054		153.188		-		153.188	-	-	-
Support (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Government Support	MIPR	Various : Various	-	4.936		6.945		7.293		-		7.293	Continuing	Continuing	Continuing
Subtotal			-	4.936		6.945		7.293		-		7.293	-	-	-
Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Tactically Exploited Reconnaissance Node (TERN)	C/TBD	Various : Various	-	0.000		1.750		1.380		-		1.380	Continuing	Continuing	Continuing
Collaborative Operations in Denied Environment (CODE)	C/Various	Various : Various	-	1.257		1.500		3.500		-		3.500	Continuing	Continuing	Continuing
Hypersonic Air-breathing Weapon Concept (HAWC)	C/Various	Various : Various	-	2.354		1.700		2.000		-		2.000	Continuing	Continuing	Continuing
Tactical Boost Glide	C/Various	Various : Various	-	4.555		1.500		3.700		-		3.700	Continuing	Continuing	Continuing

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603286E / ADVANCED AEROSPACE SYSTEMS				Project (Number/Name) AIR-01 / ADVANCED AEROSPACE SYSTEMS					
Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Vertical Take-Off and Landing (VTOL) Technology Demonstrator	C/TBD	Various : Various	-	0.000		0.500		2.150		-		2.150	Continuing	Continuing	Continuing
Aerial Reconfigurable Embedded System (ARES)	C/Various	Various : Various	-	0.504		2.000		0.000		-		0.000	0	2.504	0
Persistent Close Air Support (PCAS)	C/Various	Various : Various	-	0.355		0.000		0.000		-		0.000	0	0.355	0
Subtotal			-	9.025		8.950		12.730		-		12.730	-	-	-
Management Services (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Management Support	C/Various	Various : Various	-	6.170		8.682		9.116		-		9.116	Continuing	Continuing	Continuing
Subtotal			-	6.170		8.682		9.116		-		9.116	-	-	-
			Prior Years	FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total	Cost To Complete	Total Cost	Target Value of Contract
Project Cost Totals			-	123.292		173.631		182.327		-		182.327	-	-	-
Remarks															

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603286E / ADVANCED AEROSPACE SYSTEMS	Project (Number/Name) AIR-01 / ADVANCED AEROSPACE SYSTEMS

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
<i>Tactically Exploited Reconnaissance Node (TERN)</i>																												
Risk Reduction Testing		■																										
Large Scale On-Water Demo		■																										
SideArm Full-Scale Test								■																				
Demonstrator System Critical Design Review												■																
<i>Collaborative Operations in Denied Environment (CODE)</i>																												
System Requirements Review			■																									
Release 1: Single Vehicle Autonomy & Virtual Multi-Vehicle Demonstration								■																				
Preliminary Design Review								■																				
Critical Design Review												■																
Flight Readiness Review													■															
Release 2: Collaborative Autonomy with Few Vehicles													■															
Release 3: Advanced Supervisory Interface and Additional Vehicles																■												
<i>Hypersonic Air-breathing Weapon Concept (HAWC)</i>																												
System Requirements Review		■																										
Full-Scale Freejet Propulsion Fabrication			■																									
Preliminary Design Review								■																				
Begin design of the hypersonic air-breathing missile flight demonstration system												■																
Critical Design Review													■															

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency																				Date: February 2016								
Appropriation/Budget Activity										R-1 Program Element (Number/Name)										Project (Number/Name)								
0400 / 3										PE 0603286E / ADVANCED AEROSPACE SYSTEMS										AIR-01 / ADVANCED AEROSPACE SYSTEMS								
	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Hardware Qualification Testing																												
Tactical Boost Glide																												
Concept of Operations (ConOps)																												
System Requirements Review																												
Preliminary Design Review																												
Begin Procurement of Hardware for Demo Vehicles																												
Critical Design Review																												
Advanced Aerospace System Concepts																												
Hypersonic Propulsion Integration and Flowpath Assessments																												
Initiate Studies of Emerging Concepts																												
Trade Studies for Novel Technologies																												
Sub-System Risk Reduction Testing																												
Sub-System Feasibility Experiments																												
Technology for Enriching and Augmenting Manned - Unmanned Systems																												
Refine Final Unmanned Vehicle Design And Concept																												
Vertical Take-Off and Landing (VTOL) Technology Demonstrator																												
Preliminary Design Review																												
Source Selection for Detailed Design, Fabrication, and Flight Test																												
Final Design Review																												
Assemble Complete Aircraft																												
Distributed Fires (DFires)																												

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603286E / <i>ADVANCED AEROSPACE SYSTEMS</i>	Project (Number/Name) AIR-01 / <i>ADVANCED AEROSPACE SYSTEMS</i>

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Conduct Trade Space Analysis																												
System Requirements Review																												
Preliminary Design Review																												
Advanced Full Range Engine (AFRE)																												
Propulsion Trade Study Down Select																												
Aerial Reconfigurable Embedded System (ARES)																												
Hardware-In-The-Loop Testing																												
Flight Testing																												
Persistent Close Air Support (PCAS)																												
Live-Fire Demonstration																												
A-10 Test																												
PCAS Ground Software Prototype For UAS																												
Transition Technologies to USMC and SOCOM																												

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603286E / ADVANCED AEROSPACE SYSTEMS	Project (Number/Name) AIR-01 / ADVANCED AEROSPACE SYSTEMS	

Schedule Details

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
<i>Tactically Exploited Reconnaissance Node (TERN)</i>				
Risk Reduction Testing	2	2015	2	2015
Large Scale On-Water Demo	2	2015	2	2015
SideArm Full-Scale Test	1	2016	1	2016
Demonstrator System Critical Design Review	1	2017	1	2017
<i>Collaborative Operations in Denied Environment (CODE)</i>				
System Requirements Review	3	2015	3	2015
Release 1: Single Vehicle Autonomy & Virtual Multi-Vehicle Demonstration	2	2016	2	2016
Preliminary Design Review	2	2016	2	2016
Critical Design Review	1	2017	1	2017
Flight Readiness Review	2	2017	2	2017
Release 2: Collaborative Autonomy with Few Vehicles	2	2017	2	2017
Release 3: Advanced Supervisory Interface and Additional Vehicles	4	2017	4	2017
<i>Hypersonic Air-breathing Weapon Concept (HAWC)</i>				
System Requirements Review	2	2015	2	2015
Full-Scale Freejet Propulsion Fabrication	3	2015	3	2015
Preliminary Design Review	1	2016	1	2016
Begin design of the hypersonic air-breathing missile flight demonstration system	3	2016	3	2016
Critical Design Review	2	2017	2	2017
Hardware Qualification Testing	4	2017	4	2017
<i>Tactical Boost Glide</i>				
Concept of Operations (ConOps)	3	2015	3	2015

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603286E / <i>ADVANCED AEROSPACE SYSTEMS</i>	Project (Number/Name) AIR-01 / <i>ADVANCED AEROSPACE SYSTEMS</i>

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
System Requirements Review	3	2015	3	2015
Preliminary Design Review	2	2016	2	2016
Begin Procurement of Hardware for Demo Vehicles	3	2017	3	2017
Critical Design Review	4	2017	4	2017
<i>Advanced Aerospace System Concepts</i>				
Hypersonic Propulsion Integration and Flowpath Assessments	2	2015	2	2015
Initiate Studies of Emerging Concepts	2	2015	2	2015
Trade Studies for Novel Technologies	2	2016	2	2016
Sub-System Risk Reduction Testing	2	2017	2	2017
Sub-System Feasibility Experiments	3	2017	3	2017
<i>Technology for Enriching and Augmenting Manned - Unmanned Systems</i>				
Refine Final Unmanned Vehicle Design And Concept	4	2016	4	2016
<i>Vertical Take-Off and Landing (VTOL) Technology Demonstrator</i>				
Preliminary Design Review	1	2016	1	2016
Source Selection for Detailed Design, Fabrication, and Flight Test	1	2016	1	2016
Final Design Review	2	2017	2	2017
Assemble Complete Aircraft	3	2017	3	2017
<i>Distributed Fires (DFires)</i>				
Conduct Trade Space Analysis	3	2016	2	2017
System Requirements Review	3	2017	3	2017
Preliminary Design Review	4	2017	4	2017
<i>Advanced Full Range Engine (AFRE)</i>				
Propulsion Trade Study Down Select	3	2017	3	2017
<i>Aerial Reconfigurable Embedded System (ARES)</i>				
Hardware-In-The-Loop Testing	3	2015	3	2015

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency				Date: February 2016	
Appropriation/Budget Activity 0400 / 3		R-1 Program Element (Number/Name) PE 0603286E / ADVANCED AEROSPACE SYSTEMS		Project (Number/Name) AIR-01 / ADVANCED AEROSPACE SYSTEMS	
		Start		End	
Events by Sub Project		Quarter	Year	Quarter	Year
Flight Testing		1	2016	1	2016
Persistent Close Air Support (PCAS)					
Live-Fire Demonstration		1	2015	1	2015
A-10 Test		2	2015	2	2015
PCAS Ground Software Prototype For UAS		4	2015	4	2015
Transition Technologies to USMC and SOCOM		4	2015	1	2016

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>					R-1 Program Element (Number/Name) PE 0603287E / <i>SPACE PROGRAMS AND TECHNOLOGY</i>							
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	172.504	126.692	175.240	-	175.240	237.435	271.971	252.726	227.726	-	-
SPC-01: <i>SPACE PROGRAMS AND TECHNOLOGY</i>	-	172.504	126.692	175.240	-	175.240	237.435	271.971	252.726	227.726	-	-

A. Mission Description and Budget Item Justification

The Space Programs and Technology program element is budgeted in the Advanced Technology Development budget activity because it addresses high payoff opportunities to dramatically reduce costs associated with advanced space systems and provides revolutionary new system capabilities for satisfying current and projected military missions.

A space force structure that is robust against attack represents a stabilizing deterrent against adversary attacks on space assets. The keys to a secure space environment are situational awareness to detect and characterize potential threats, a proliferation of assets to provide robustness against attack, ready access to space, and a flexible infrastructure for maintaining the capabilities of on-orbit assets. Ready access to space requires the delivery of capabilities, replenishment of supplies into orbit, and rapid manufacturing of affordable space capabilities. Developing space access and spacecraft servicing technologies will lead to reduced ownership costs of space systems and new opportunities for introducing technologies for the exploitation of space.

Systems development is also required to increase the interactivity of space systems, space-derived information and services with terrestrial users. Studies under this project include technologies and systems that will enable satellites and microsatellites to operate more effectively by increasing maneuverability, survivability, and situational awareness; enabling concepts include novel power/propulsion/propellants, unique manufacturing or assembly processes; and precision control of multi-payload systems.

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	179.883	126.692	130.091	-	130.091
Current President's Budget	172.504	126.692	175.240	-	175.240
Total Adjustments	-7.379	0.000	45.149	-	45.149
• Congressional General Reductions	0.000	0.000			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	-1.900	0.000			
• SBIR/STTR Transfer	-5.479	0.000			
• TotalOtherAdjustments	-	-	45.149	-	45.149

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)		R-1 Program Element (Number/Name) PE 0603287E / SPACE PROGRAMS AND TECHNOLOGY		
<u>Change Summary Explanation</u> FY 2015: Decrease reflects reprogrammings and the SBIR/STTR transfer. FY 2016: N/A FY 2017: Increase reflects expanded requirements in the Experimental Spaceplane One (XS-1), Robotic Servicing of Geostationary Satellites (RSGS), and Radar Net programs.				
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Title: Experimental Spaceplane One (XS-1)		25.000	30.000	50.500
Description: The XS-1 program will mature the technologies and operations for low cost, persistent and responsive space access and global reach. Past efforts have identified and demonstrated critical enabling technologies including composite or light weight structures, propellant tanks, thermal protection systems, rocket propulsion and advanced avionics/software. A critically important technology gap is integration into a flight demonstration able to deliver aircraft-like operability. The program will validate key technologies on the ground, and then fabricate an X-Plane to demonstrate: 1) 10 flights in 10 days, 2) up to Mach 10+ flight, and 3) design capable of a 10X lower cost space access for cargos from 3,000-5,000 lbs to low earth orbit. A key goal is validating the critical technologies for a wide range of next generation high speed aircraft enabling new military capabilities including worldwide reconnaissance, global transport, small responsive space access aircraft and affordable spacelift. The anticipated transition partners are the Air Force, Navy and commercial sector.				
FY 2015 Accomplishments: - Conducted risk reduction studies for propulsion, thermal protection systems, guidance/avionics, composite materials, propellant tanks and space based communications. - Conducted a mid-phase Conceptual Design and Systems Requirements Review. - Conducted component, wind tunnel, propulsion, cryogenic propellant tank, thermal protection, aero-elasticity testing, ground operations and subsystem testing and verification. - Continued to develop detailed XS-1 designs including mass properties, configuration, aerodynamic, trajectory and thermal protection data. - Conducted a Preliminary Design Review and selected design for technology risk reduction.				
FY 2016 Plans: - Develop detailed finite element model structural and thermal analysis for the XS-1 design. - Perform aerodynamic Computational Fluid Dynamics analysis and initiate hypersonic wind tunnel and upper stage separation testing for the XS-1 design to verify aerodynamic models. - Conduct component demonstration and validation ground tests for cryogenic propellant tanks, thermal protection, wing tip aero-elasticity, and additive manufacture of propulsion components and flight demonstrations for take-off and landing operations.				

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide I BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603287E / <i>SPACE PROGRAMS AND TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Validate recurring operational costs via discrete event simulations for ground operations and upper stage unit cost analysis and integration costs. - Complete the system and subsystem designs, mass properties and configuration required to support the integrated vehicle design. - Finalize the concept of operation including the maintenance concept, performance, trajectories and design reference missions. - Develop initial plan to accomplish ground operations, facility modifications and flight demonstration. - Coordinate with the Federal Aviation Administration (FAA), DoD ranges and spaceports to accomplish preliminary flight test planning. FY 2017 Plans: - Complete hypersonic wind tunnel and upper stage separation testing for the XS-1 and incorporate in the flight vehicle design. - Complete structure, thermal protection, and cryogenic tank demonstration and validation testing and incorporate results in the flight vehicle design. - Complete propulsion component demonstration and validation testing. - Complete airframe/propulsion integration for incorporation in the XS-1 flight vehicle design. - Mature the XS-1 concept through critical design review including complete configuration, aero-thermodynamics, six degree of freedom trajectory calculations, mass properties and associated ground systems. - Conduct Critical Design Review to approve XS-1 vehicle design for component acquisition, fabrication, assembly, and integration. - Complete design for all launch facilities/modifications and mature range planning including ground and flight test operations, and submittal of range documentation supporting operational requirements. - Coordinate with the FAA, DoD ranges and commercial spaceports. - Begin fabrication of flight and ground system hardware.				
Title: Phoenix Description: To date, servicing operations have never been conducted on spacecraft beyond low earth orbit (LEO). A large number of national security and commercial space systems operate at geosynchronous earth orbit (GEO) altitudes; furthermore, many end-of-life or failed spacecraft drift without control through portions of the GEO belt, creating a growing hazard to operational spacecraft. Technologies for servicing of spacecraft with the expectation that such servicing would involve a mix of highly autonomous and remotely (i.e., ground-based) tele-operated robotic systems have been previously pursued. The Phoenix program will build upon these legacy technologies, tackling the more complex GEO environment and expanding beyond pure traditional servicing functions. The program will examine utilization of a new commercial ride-along system to GEO called Payload Orbital Delivery (POD) system, supporting hardware delivery for upgrading, repairing, assembling, and reconfiguring satellites. In addition, the program will include a LEO flight experiment focused on satlets, modular building blocks for space systems, as		55.000	19.000	8.740

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603287E / <i>SPACE PROGRAMS AND TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions) a path of risk reduction for modular assembly on orbit. The anticipated transition partners are the Air Force and the commercial spacecraft servicing providers.		FY 2015	FY 2016	FY 2017
FY 2015 Accomplishments: - Completed delta critical design of satlets and of communications system for early LEO experiment. - Completed delta critical design of POD for first GEO flight. - Validated specific servicing mission types that maximize value for commercial and DoD satellite operators. - Began fabrication of robotic hardware and software. FY 2016 Plans: - Deliver early LEO satlet experiment equipment to launch integrator. - Launch early LEO satlet experiment and conduct experiment operations. - Complete delta critical design of satlets per lessons learned from LEO experiment. - Develop PODs payload hardware for launch. FY 2017 Plans: - Launch POD and conduct on-orbit testing.				
Title: Robotic Servicing of Geostationary Satellites (RSGS) Description: A large number of national security and commercial space systems operate at geosynchronous earth orbit (GEO), providing persistence and enabling ground station antennas to point in a fixed direction. Technologies for servicing of GEO spacecraft would involve a mix of highly automated and remotely operated (from Earth) robotic systems. The Robotic Servicing of Geostationary Satellites (RSGS) program, an outgrowth of the Phoenix program budgeted within this Project, seeks to establish the capability to acquire robotic services in GEO suitable for a variety of potential servicing tasks, in full collaboration and cooperation with existing satellite owners, and with sufficient propellant for several years of follow-on capability. Key RSGS challenges include robotic tool/end effector requirements, efficient orbital maneuvering of a servicing vehicle, robotic arm systems, automation of certain spacecraft operations, and development of the infrastructure for coordinated control between the servicer and client spacecraft operations teams. The anticipated transition is to a commercial partner who will provide the satellite to carry the robotic payload and who will operate the robotic servicer.		4.000	12.000	33.000
FY 2015 Accomplishments: - Developed detailed requirements developed from mission description and commercial operator needs. - Completed system requirements review of robotic servicing system including robotic arms and tool docking system. FY 2016 Plans: - Continue development of servicer robotic payload initiated under the Phoenix program.				

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603287E / <i>SPACE PROGRAMS AND TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Conduct studies of suitable satellites to carry the robotic payload. - Establish system requirements for the robotic payload in accordance with primary missions. FY 2017 Plans: - Select provider for satellite to carry robotic payload. - Develop interface definition between robotic payload and satellite. - Begin flight software coding. - Begin development of operator workstations. - Begin procurement of long-life space hardware for robotic payload and instrumentation.				
Title: Space Surveillance Telescope (SST) Description: The Space Surveillance Telescope (SST) program has developed and demonstrated an advanced ground-based optical system to enable detection and tracking of faint objects in space, while providing rapid, wide-area search capability. A major goal of the SST program, to develop the technology for large curved focal surface array sensors to enable an innovative telescope design combining high detection sensitivity, short focal length, wide field of view, and rapid step-and-settle to provide orders of magnitude improvements in space surveillance has been achieved. This capability enables ground-based detection of un-cued objects in deep space for purposes such as asteroid detection and space defense missions. The initial program is transitioning to Air Force Space Command. The SST Australia effort will provide a further operational demonstration of the SST at the Naval Communication Station Harold E. Holt near Exmouth, Western Australia. Such a location presents a more operationally relevant demonstration, with a richer and more interesting population of SSA targets in geosynchronous orbit. A demonstration in New Mexico will validate telescope performance comparable to the requirement in Australia. In addition, the demonstration will generate data for analysis and fusion efforts, which will be used to further refine and evaluate data processing techniques, such as those developed under the data fusion effort. This program will address technical challenges which may arise from an Australian site, including adaptations to a different telescope environment, and the logistical and communications challenges presented by a site significantly more remote than the current SST location. FY 2015 Accomplishments: - Continued to refine SST relocation plan jointly with Air Force Space Command (AFSPC) and the Australian Department of Defense partners. - Conducted SST sustainment studies.		9.000	9.000	10.000

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603287E / <i>SPACE PROGRAMS AND TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Developed capability to deliver SST data to Joint Space Operations Center (JSpOC) through Non-Traditional Data Pre-Processor (NDPP). FY 2016 Plans: - Make improvements to Wide Field Camera (WFC) #2 for improved SST capability. - Install and characterize WFC #2 at White Sands Missile Range (WSMR) site and demonstrate performance improvement. - Support Joint Space Operations Center (JsPOC) data delivery. - Develop plan to transition SST to AFSPC. FY 2017 Plans: - Complete required documentation for Australian facility. - Support transition to the Air Force.				
Title: Radar Net Description: The Radar Net program will develop lightweight, low power, wideband capability for radio frequency (RF) communications and remote sensing for a space based platform. The enabling technologies of interest are extremely lightweight and space capable deployable antenna structures. Current deployable antenna options have not been sufficiently developed to be dependable on small payload launches, leaving current capabilities trending to large and more costly launch systems. These launch systems are expected to have long operational lifetimes, which can leave them behind the pace of state of the art technical developments. The technologies developed under Radar Net will enable small, low-cost sensor launches on short timescales with rapid technology refresh capabilities. FY 2016 Plans: - Develop a detailed system architecture assessment. - Begin cubesat deployable antenna risk reduction. - Commence thermal cycling, power availability, and electrical system analysis. - Conduct pathfinder spacecraft Critical Design Review (CDR). - Conduct prototype Preliminary Design Review (PDR). FY 2017 Plans: - Conduct prototype CDR. - Conduct pathfinder laboratory and ground tests. - Conduct pathfinder flight qualification. - Launch and conduct pathfinder on-orbit demonstration of multiple deployable antenna technologies. - Demonstrate software defined radio RF capability on appropriate platform. - Perform risk reduction signal processing demonstration.		-	15.000	45.000

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603287E / <i>SPACE PROGRAMS AND TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Integrate results from applications study and pathfinder/risk reduction into prototype design. - Perform early system design reviews.				
Title: Hallmark Description: The Hallmark program seeks to demonstrate a space Battle Management Command and Control (BMC2) capability to provide U.S. senior leadership the tools needed to effectively manage space assets in real time. The program will develop command and control decision tools for full-spectrum space operations, management, and control from peace to potential conflict. Hallmark will demonstrate the ability to increase space threat awareness via use of multi-data fusion and time-relevant sensor tasking. The program will also improve the ability to protect against threats by use of modeling and simulation tools for both natural and adversary intent determination and course of action development. The program will employ comprehension and visualization techniques to increase commander and operator awareness to transform information to knowledge and effectively communicate and facilitate time-critical decision making. The anticipated transition partner is the Air Force. FY 2016 Plans: - Initiate space BMC2 interactive simulation environment development. - Conduct demonstration of integrated Government Furnished Equipment (GFE) space BMC2 tools. - Perform demonstration of space BMC2 interactive simulation environment. - Develop a research and development test bed to facilitate the rapid injection of new technologies into the Joint Space Operations Center (JSpOC) and Joint Interagency Coalition Space Operations Center (JICSpOC). - Initiate the cognitive evaluation of operators and decision makers in a demonstration environment to maximize comprehension. - Complete preliminary system design. - Initiate real-time decision tools design development. - Develop sensor data fusion algorithms. - Define course of action data scheme. - Develop intuitive applications and adaptive understanding capabilities for the next-generation space information fusion center. - Define integration of space BMC2 interactive simulation environment with tools, fusion algorithms and data schemes. FY 2017 Plans: - Perform existing tool integration. - Develop modeling and simulation infrastructure. - Complete algorithm prototypes. - Complete study of extensible framework. - Commence integration of existing space situational awareness, indications and warning, course of action, and decision support tools.		-	10.000	28.000

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603287E / <i>SPACE PROGRAMS AND TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Demonstrate and document integrated tools, algorithms and data schemes.				
Title: Airborne Launch Assist Space Access (ALASA) Description: The ALASA program seeks to make access to space more affordable by reducing the cost per launch to under one million dollars per flight for 100 lb payloads to low earth orbit. In addition, the program seeks to improve the responsiveness of space access by reducing the interval from call-up to launch to a single day. This enables rapid delivery of spacecraft in response to evolving situations, such as a humanitarian crisis or unexpected conflict, and is accomplished by developing rapid mission planning tools which streamline existing range processes, and automated flight safety systems which reduce reliance on expensive and fragile range infrastructure. These tools enable the program's third goal: to escape the limitations of fixed launch sites by achieving a greater flexibility in the direction and location of launch. Challenges include, but are not limited to: development of a high-energy, low cost monopropellant, development of alternatives to current range processes, and achieving a cost per flight of one million dollars, including range support costs, to deploy satellites on the order of one hundred pounds. The anticipated transition partners are the Air Force and the emerging commercial space launch industry. FY 2015 Accomplishments: - Conducted propellant production, handling activities, and propellant ignition testing. - Conducted analysis of launch performance metrics and identified opportunities for system design and integration optimization. - Investigated and developed alternative propulsion approach. - Performed system redesign to simplify interfaces and improve payload capacity. FY 2016 Plans: - Complete propellant characterization to determine operating envelope. - Conduct engine testing to determine constraints and obtain thermal management and performance measurements. - Develop risk assessment and perform modeling and testing of spaced based telemetry, planning tools, and flight termination technology which could decrease impact of launch on commercial air traffic. - Assess alternative propellants and launch systems.		60.000	20.000	-
Title: Optical Aperture Self-Assembly in Space (OASIS) Description: The Optical Apertures Self-assembling in Space program seeks to demonstrate the feasibility of constructing large optical apertures in orbit from a number of smaller modular components that self-organize in space. The program will demonstrate the technologies needed to assemble a large (>5m) and near-diffraction limited optical aperture from modular components that are launched as separate payloads. The program will include a scalable zero-g demonstration of a functional optical system that maintains the precision and large-scale physical stability required, and utilizes at least one segmented optical surface. This program will address technical challenges of precision mechanical assembly from modular components, multiple object rendezvous and coupling in space, and active surface measurement, compensation and control. Modular construction		2.000	6.000	-

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Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603287E / <i>SPACE PROGRAMS AND TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions) in space is intrinsically more challenging than ground-based assembly in that there is not necessarily any measurement and support infrastructure and equipment available, such as interferometer test towers. Therefore, the modular pieces and system design must include self-contained measurement and alignment capabilities to be employed after or during assembly. The OASIS program will demonstrate the feasibility of assembling complex and highly precise structures in space which, in assembled form, are larger than the capacity of any existing or planned space launch vehicle. This capability could enable a number of surveillance and communications instruments in orbit that are not possible today or in the near future under the current paradigm. The anticipated transition partners are the Air Force, Navy and commercial sector. FY 2015 Accomplishments: - Investigated essential technologies to facilitate self-organizing robotic construction in space. - Developed improved piezopolymer controlled deformable mirrors which can be deployed in a self-assembling orbital optical aperture. - Developed a Photonic Integrated Circuit (PIC) for a proof of concept interferometry demonstration, to enable simultaneous wide angle and zoom capabilities from a single device with no moving parts. - Performed risk reduction activities on strain-deployed, piezo-aligned, lightweight sparse aperture optical concept to support orbital Intelligence, Surveillance, and Reconnaissance (ISR). FY 2016 Plans: - Continue risk reduction activities on strain-deployed, piezo-aligned, lightweight sparse aperture optical concept to support orbital Intelligence, Surveillance, and Reconnaissance (ISR). - Conduct laboratory demonstration of high resolution capability with light weight optics by leveraging a precision interferometric approach combined with novel image reconstruction algorithm and PIC, which will provide both simultaneous wide angle and zoom capabilities on the same device with no moving parts. - Construct improved piezopolymer controlled deformable mirrors.		FY 2015	FY 2016	FY 2017
Title: Space Domain Awareness (SDA) Description: The goal of the Space Domain Awareness (SDA) program is to develop and demonstrate an operational framework and responsive defense application to enhance the availability of vulnerable space-based resources. Current space surveillance sensors cannot detect, track, or determine the future location and threat potential of small advanced technology spacecraft in deep space orbits, where a majority of DoD spacecraft are located. Additionally, servicing missions to geosynchronous earth (GEO) orbits will require exquisite situational awareness, from ultra-high-accuracy debris tracking for mission assurance at GEO orbits to high resolution imaging of GEO spacecraft for service mission planning. SDA will investigate revolutionary technologies in two areas: 1) advanced space surveillance sensors to better detect, track, and characterize space objects, with an emphasis on deep space objects, and 2) space surveillance data collection, data archival,		17.504	5.692	-

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide I BA 3: Advanced Technology Development (ATD)</i>		R-1 Program Element (Number/Name) PE 0603287E / <i>SPACE PROGRAMS AND TECHNOLOGY</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
and data processing/fusion to provide automated data synergy. The resulting increase in space domain awareness will enhance overall space safety of flight, and allow space operators to make informed, timely decisions. The SDA program will leverage data fusion and advanced algorithms developed under the Space Surveillance Telescope (SST) program, as well as seek to exploit new ground-breaking technologies across the electromagnetic spectrum and utilize already existing sensor technology in nontraditional or exotic ways, to bring advanced capabilities to the space domain. SDA will demonstrate new approaches to collection of data utilizing a variety of collection modalities, ranging from fusion of observations from non-traditional sources, such as amateur astronomers, to evaluation of sparse aperture imaging techniques.				
FY 2015 Accomplishments:				
- Expanded the SpaceView amateur network to additional nodes including Australia locations. - Incorporated international data sources into SDA database. - Initiated data ingest from the StellarView network of academic astronomy data providers. - Commenced Phase 1 of an un-cued low inclined LEO object detection capability. - Performed database verification on collected data; demonstrated metric and radiometric accuracy. - Studied the application of coherent and quantum detectors to Space Domain Awareness challenges of object detection and imaging. - Initiated Real-Time Space Domain Awareness design development. - Completed development and took delivery of bias estimation, bias aware, bias-aware track generation software, received initial value assessment of data containing biases provided to enhance SDA.				
FY 2016 Plans:				
- Complete an initial capability demonstration of a collaborative network of distributed sensors and users to generate timely, accurate and actionable space indications and warnings. - Integrate all data providers and first generation algorithms on the SDA database to autonomously detect biases, estimate uncertainties, and leverage non-accredited information for real time SDA. - Continue value assessment of data containing biases provided to SDA database. - Expand the portfolio of modalities contributing to SDA to include RADAR data providers. - Integrate SDA database with the US Space Command non-traditional data preprocessor. - Conduct capability demonstration of collaborative network of distributed sensors and users. - Perform and document analysis of algorithm performance.				
Accomplishments/Planned Programs Subtotals		172.504	126.692	175.240
D. Other Program Funding Summary (\$ in Millions)				
N/A				

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide I BA 3: Advanced Technology Development (ATD)</i>	R-1 Program Element (Number/Name) PE 0603287E / <i>SPACE PROGRAMS AND TECHNOLOGY</i>	
D. Other Program Funding Summary (\$ in Millions)		
Remarks		
E. Acquisition Strategy N/A		
F. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.		

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603287E / SPACE PROGRAMS AND TECHNOLOGY				Project (Number/Name) SPC-01 / SPACE PROGRAMS AND TECHNOLOGY					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Airborne Launch Assist Space Access (ALASA)	C/CPFF	The Boeing Company : CA	-	53.964	Oct 2014	0.000		0.000		-		0.000	0	53.964	0
Airborne Launch Assist Space Access (ALASA)	C/Various	Various : Various	-	0.000		14.750		0.000		-		0.000	0	14.750	0
Experimental Spaceplane One (XS-1)	C/Various	The Boeing Company : CA	-	5.857	Oct 2014	2.504		0.000		-		0.000	Continuing	Continuing	Continuing
Experimental Spaceplane One (XS-1)	C/CPFF	Northrop Grumman : CA	-	5.427	Dec 2014	2.120		0.000		-		0.000	Continuing	Continuing	Continuing
Experimental Spaceplane One (XS-1)	C/Various	Various : Various	-	11.466		5.376		0.000		-		0.000	Continuing	Continuing	Continuing
Experimental Spaceplane One (XS-1)	C/TBD	TBD : TBD	-	0.000		17.163		44.455		-		44.455	Continuing	Continuing	Continuing
Phoenix	MIPR	Naval Research Laboratory : Various	-	15.766	Nov 2014	15.375		5.900		-		5.900	Continuing	Continuing	Continuing
Phoenix	C/Various	Various : Various	-	34.284		1.915		2.053		-		2.053	Continuing	Continuing	Continuing
Robotic Servicing of Geostationary Satellites (RSGS)	MIPR	Naval Research Laboratory : Various	-	2.000	Nov 2014	4.000		15.000		-		15.000	Continuing	Continuing	Continuing
Robotic Servicing of Geostationary Satellites (RSGS)	C/Various	Various : Various	-	1.640		1.500		5.350		-		5.350	Continuing	Continuing	Continuing
Robotic Servicing of Geostationary Satellites (RSGS)	C/TBD	TBD : TBD	-	0.000		5.420		10.180		-		10.180	Continuing	Continuing	Continuing
Space Surveillance Telescope (SST)	SS/CPFF	Massachusetts Institute of Technology : MA	-	8.190	Nov 2014	8.190		9.100		-		9.100	Continuing	Continuing	Continuing
Radar Net	C/TBD	Various : Various	-	0.000		14.100		36.950		-		36.950	Continuing	Continuing	Continuing
Hallmark	C/TBD	Various : Various	-	0.000		9.100		20.480		-		20.480	Continuing	Continuing	Continuing
Optical Aperture Self-Assembly in Space (OASIS)	C/Various	Various : Various	-	1.820		5.460		0.000		-		0.000	0	7.280	0

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603287E / SPACE PROGRAMS AND TECHNOLOGY				Project (Number/Name) SPC-01 / SPACE PROGRAMS AND TECHNOLOGY					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Space Domain Awareness (SDA)	C/Various	Various : Various	-	15.929		5.180		0.000		-		0.000	0	21.109	0
Subtotal			-	156.343		112.153		149.468		-		149.468	-	-	-
Support (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Government Support	MIPR	Various : Various	-	6.900		5.068		7.010		-		7.010	Continuing	Continuing	Continuing
Subtotal			-	6.900		5.068		7.010		-		7.010	-	-	-
Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Airborne Launch Assist Space Access (ALASA)	C/Various	Various : Various	-	0.636		3.000		0.000		-		0.000	0	3.636	0
Experimental Spaceplane One (XS-1)	C/Various	Various : Various	-	0.000		0.136		1.500		-		1.500	Continuing	Continuing	Continuing
Robotic Servicing of Geostationary Satellites (RSGS)	C/TBD	Various : Various	-	0.000		0.000		0.500		-		0.500	Continuing	Continuing	Continuing
Radar Net	C/TBD	Various : Various	-	0.000		0.000		3.000		-		3.000	Continuing	Continuing	Continuing
Hallmark	C/TBD	Various : Various	-	0.000		0.000		5.000		-		5.000	Continuing	Continuing	Continuing
Subtotal			-	0.636		3.136		10.000		-		10.000	-	-	-

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016		
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603287E / SPACE PROGRAMS AND TECHNOLOGY				Project (Number/Name) SPC-01 / SPACE PROGRAMS AND TECHNOLOGY				

Management Services (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Management Support	C/Various	Various : Various	-	8.625		6.335		8.762		-		8.762	Continuing	Continuing	Continuing
Subtotal			-	8.625		6.335		8.762		-		8.762	-	-	-

	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	Cost To Complete	Total Cost	Target Value of Contract
Project Cost Totals	-	172.504	126.692	175.240	-	175.240	-	-	-

Remarks

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603287E / SPACE PROGRAMS AND TECHNOLOGY	Project (Number/Name) SPC-01 / SPACE PROGRAMS AND TECHNOLOGY	

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Airborne Launch Assist Space Access (ALASA)																												
Propellant Ignition and Interim Hazard Classification Testing																												
Engine Testing																												
Experimental Spaceplane One (XS-1)																												
Design & Risk Reduction																												
Preliminary Design Review																												
Wind Tunnel Testing																												
Fabrication and Flight Test																												
Complete integrated vehicle design																												
Propulsion Demonstration, Validation, and Design Integration																												
Phoenix																												
Fabrication of Robotic Hardware and Software																												
Completed Delta Critical Design of POD for First GEO Flight																												
Completed Delta Critical Design of Satlets and of Communications System for Early LEO Experiment																												
Launch Early LEO Satlet Experiment and Conduct Experiment Operations																												
Launch POD and Conduct On-Orbit Testing																												
Robotic Servicing of Geostationary Satellites (RSGS)																												
Develop Detailed Program Requirements																												

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency

Date: February 2016

Appropriation/Budget Activity

0400 / 3

R-1 Program Element (Number/Name)

PE 0603287E / SPACE PROGRAMS AND TECHNOLOGY

Project (Number/Name)

SPC-01 / SPACE PROGRAMS AND TECHNOLOGY

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Continue Development of Servicer Robotic Payload																												
Conduct Studies of Suitable Satellites to Carry the Robotic Payload																												
Begin Development of Operator Workstations																												
Develop Interface Definition Between Robotic Payload and Satellite																												
Space Surveillance Telescope (SST)																												
Refine SST relocation plan with Air Force Space Command (AFSPC) and the Australian Department																												
Wide Field Camera #2 Demonstration																												
Develop Plan to Transition SST to AFSPC																												
Finalize Plans to Remove and Recoat Mirrors at Kitt Peak Arizona																												
Radar Net																												
Risk Reduction																												
System Design																												
On-Orbit Risk Reduction Demonstration																												
Signal Processing Risk Reduction Demonstration																												
System Conceptual Design Review																												
Hallmark																												
Initiate space BMC2 interactive simulation environment development																												
Complete Architecture Definition																												

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency																			Date: February 2016									
Appropriation/Budget Activity 0400 / 3									R-1 Program Element (Number/Name) PE 0603287E / SPACE PROGRAMS AND TECHNOLOGY									Project (Number/Name) SPC-01 / SPACE PROGRAMS AND TECHNOLOGY										
	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Demonstrate and document integrated tools, algorithms and data schemes																												
Develop modeling and simulation infrastructure																												
Optical Aperture Self-Assembly in Space (OASIS)																												
Developed Improved Piezopolymer Controlled Deformable Mirrors																												
Conduct final demonstration of Image Quality Refinement																												
Space Domain Awareness (SDA)																												
Identify Advanced Collection Technique Need																												
Second Data Buy Option																												
Advanced Collection Technique First Collect																												
Complete initial capability demonstration																												

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603287E / <i>SPACE PROGRAMS AND TECHNOLOGY</i>	Project (Number/Name) SPC-01 / <i>SPACE PROGRAMS AND TECHNOLOGY</i>	

Schedule Details

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
<i>Airborne Launch Assist Space Access (ALASA)</i>				
Propellant Ignition and Interim Hazard Classification Testing	2	2015	2	2016
Engine Testing	3	2016	4	2016
<i>Experimental Spaceplane One (XS-1)</i>				
Design & Risk Reduction	1	2015	2	2015
Preliminary Design Review	1	2015	3	2015
Wind Tunnel Testing	2	2015	3	2015
Fabrication and Flight Test	4	2016	4	2017
Complete integrated vehicle design	1	2017	4	2017
Propulsion Demonstration, Validation, and Design Integration	2	2017	3	2017
<i>Phoenix</i>				
Fabrication of Robotic Hardware and Software	1	2015	4	2017
Completed Delta Critical Design of POD for First GEO Flight	3	2015	3	2015
Completed Delta Critical Design of Satlets and of Communications System for Early LEO Experiment	4	2015	4	2015
Launch Early LEO Satlet Experiment and Conduct Experiment Operations	2	2016	4	2016
Launch POD and Conduct On-Orbit Testing	2	2017	3	2017
<i>Robotic Servicing of Geostationary Satellites (RSGS)</i>				
Develop Detailed Program Requirements	2	2015	2	2015
Continue Development of Servicer Robotic Payload	1	2016	4	2016
Conduct Studies of Suitable Satellites to Carry the Robotic Payload	3	2016	1	2017
Begin Development of Operator Workstations	1	2017	1	2017

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603287E / SPACE PROGRAMS AND TECHNOLOGY	Project (Number/Name) SPC-01 / SPACE PROGRAMS AND TECHNOLOGY		
	Start		End	
Events by Sub Project	Quarter	Year	Quarter	Year
Develop Interface Definition Between Robotic Payload and Satellite	2	2017	4	2017
Space Surveillance Telescope (SST)				
Refine SST relocation plan with Air Force Space Command (AFSPC) and the Australian Department	1	2015	4	2015
Wide Field Camera #2 Demonstration	2	2016	3	2016
Develop Plan to Transition SST to AFSPC	4	2016	4	2016
Finalize Plans to Remove and Recoat Mirrors at Kitt Peak Arizona	1	2017	1	2017
Radar Net				
Risk Reduction	1	2016	3	2017
System Design	3	2016	4	2017
On-Orbit Risk Reduction Demonstration	3	2017	3	2017
Signal Processing Risk Reduction Demonstration	3	2017	3	2017
System Conceptual Design Review	3	2017	3	2017
Hallmark				
Initiate space BMC2 interactive simulation environment development	3	2016	3	2016
Complete Architecture Definition	3	2016	4	2016
Demonstrate and document integrated tools, algorithms and data schemes	2	2017	2	2017
Develop modeling and simulation infrastructure	2	2017	4	2017
Optical Aperture Self-Assembly in Space (OASIS)				
Developed Improved Piezopolymer Controlled Deformable Mirrors	2	2015	2	2015
Conduct final demonstration of Image Quality Refinement	2	2016	2	2016
Space Domain Awareness (SDA)				
Identify Advanced Collection Technique Need	3	2015	3	2015
Second Data Buy Option	3	2015	3	2015
Advanced Collection Technique First Collect	2	2016	2	2016
Complete initial capability demonstration	4	2016	4	2016

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>	R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>

COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	81.119	76.021	49.807	-	49.807	74.033	87.960	119.359	165.172	-	-
MT-12: <i>MEMS AND INTEGRATED MICROSYSTEMS TECHNOLOGY</i>	-	13.363	2.200	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-
MT-15: <i>MIXED TECHNOLOGY INTEGRATION</i>	-	67.756	73.821	49.807	-	49.807	74.033	87.960	119.359	165.172	-	-

A. Mission Description and Budget Item Justification

The Advanced Electronics Technologies program element is budgeted in the Advanced Technology Development Budget Activity because it seeks to design and demonstrate state-of-the-art manufacturing and processing technologies for the production of various electronics and microelectronic devices, sensor systems, actuators and gear drives that have military applications and potential commercial utility. Introduction of advanced product design capability and flexible, scalable manufacturing techniques will enable the commercial sector to rapidly and cost-effectively satisfy military requirements.

The MicroElectroMechanical Systems (MEMS) and Integrated Microsystems Technology program is a broad, cross-disciplinary initiative to merge computation and power generation with sensing and actuation to realize a new technology for both perceiving and controlling weapons systems and battlefield environments. Using fabrication processes and materials similar to those used to make microelectronic devices, MEMS applies the advantages of miniaturization, multiple components and integrated microelectronics to the design and construction of integrated electromechanical and electro-chemical-mechanical systems. The MEMS program addresses issues ranging from the scaling of devices and physical forces to new organization and control strategies for distributed, high-density arrays of sensor and actuator elements. These issues include microscale power and actuation systems as well as microscale components that survive harsh environments. Thermal management technologies will develop heat resistant thermal layers to provide efficient operation for cooling electronic devices.

The Mixed Technology Integration project funds advanced development and demonstrations of selected basic and applied electronics research programs. Examples of activities funded in this project include, but are not limited to: (1) component programs that integrate mixed signal (analog and digital; photonic and electronic) or mixed substrate (Gallium Nitride, Gallium Arsenide, Indium Phosphide, or Silicon Germanium with CMOS) technology that will substantially improve the capability of existing components and/or reduce size, weight and power requirements to a level compatible with future warfighter requirements; (2) development and demonstration of brassboard system applications in such areas as laser weaponry or precision navigation and timing to address mid-term battlefield enhancements; and (3) novel technological combinations (i.e. photonics, magnetics, frequency attenuators) that could yield substantial improvement over current systems.

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>	R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	92.246	79.021	87.381	-	87.381
Current President's Budget	81.119	76.021	49.807	-	49.807
Total Adjustments	-11.127	-3.000	-37.574	-	-37.574
• Congressional General Reductions	0.000	-3.000			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	-8.317	0.000			
• SBIR/STTR Transfer	-2.810	0.000			
• TotalOtherAdjustments	-	-	-37.574	-	-37.574

Change Summary Explanation

FY 2015: Decrease reflects reprogrammings and the SBIR/STTR transfer.

FY 2016: Decrease reflects congressional reduction.

FY 2017: Decrease reflects completion of several Endurance, Diverse & Accessible Heterogeneous Integration (DAHI), and FLASH - Scaling Fiber Arrays at Near Perfect Beam Quality program milestones.

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>				Project (Number/Name) MT-12 / <i>MEMS AND INTEGRATED MICROSYSTEMS TECHNOLOGY</i>			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
MT-12: <i>MEMS AND INTEGRATED MICROSYSTEMS TECHNOLOGY</i>	-	13.363	2.200	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-

A. Mission Description and Budget Item Justification

The MicroElectroMechanical Systems (MEMS) and Integrated Microsystems Technology project funds a broad, cross-disciplinary initiative to merge computation and power generation with sensing and actuation to realize a new technology for both perceiving and controlling weapons systems and battlefield environments. Using fabrication processes and materials similar to those used to make microelectronic devices, MEMS applies the advantages of miniaturization, multiple components and integrated microelectronics to the design and construction of integrated electromechanical and electro-chemical-mechanical systems. The MEMS program addresses issues ranging from the scaling of devices and physical forces to new organization and control strategies for distributed, high-density arrays of sensor and actuator elements. These issues include microscale precision, navigation, and timing systems as well as microscale components that survive harsh environments. These MEMS systems need to operate in a variety of thermal and vibration environments to make them tactically relevant.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Micro-Technology for Positioning, Navigation, and Timing (Micro PN&T)	13.363	2.200	-
Description: The Micro-Technology for Positioning, Navigation, and Timing (Micro-PNT) program is developing low-Cost, Size, Weight, and Power (CSWaP) inertial sensors and timing sources for navigation in GPS degraded environments, primarily focusing on the development of miniature solid state and atomic gyroscopes and clocks. Both classes of sensors are currently unsuitable for small platform or dismount soldier applications. Micro Electro-Mechanical Systems (MEMS) sensors have limited performance but excellent CSWaP, while atomic sensors are capable of excellent performance but are limited to laboratory experiments due to complexity and high CSWaP. Micro-PNT is advancing both technology approaches by improving the performance of MEMS inertial sensors and by miniaturizing atomic devices. Ultimately, low-CSWaP inertial sensors and clocks will enable ubiquitous guidance and navigation on all platforms, including guided munitions, unmanned aerial vehicles (micro-UAVs), and mounted and dismounted soldiers.			
Successful realization of Micro-PNT requires development of new microfabrication processes and novel material systems for fundamentally different sensing modalities, understanding of error sources at the micro-scale, and development of miniature inertial sensors based on atomic physics. Innovative microfabrication techniques under development will allow co-fabrication of dissimilar devices on a single chip, such that clocks, gyroscopes, accelerometers, and calibration stages can be integrated into a small, low power architecture. The program is developing miniature inertial sensors based on atomic interferometry and nuclear magnetic resonance. Ancillary research efforts for this program are funded within PE 0602716E, Project ELT-01.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>	Project (Number/Name) MT-12 / <i>MEMS AND INTEGRATED MICROSYSTEMS TECHNOLOGY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
<i>FY 2015 Accomplishments:</i> - Fabricated low loss shell resonators for gyroscope applications with ring down time > 100 seconds. - Demonstrated a miniature, self-contained atomic gyroscope with Angle Random Walk (ARW) < 0.05 degrees/sqrt(hr) and bias stability < 0.01 degrees/hr. - Demonstrated self-calibrating MEMS gyroscope with long-term scale factor and bias of < 10 parts per million (ppm) of full scale range. - Demonstrated inertial sensing in both cold-atom and thermal atomic beam atom interferometers. - Demonstrated operation of a MEMS tuning fork gyroscope (TFG) on integrated rotation/calibration stage. <i>FY 2016 Plans:</i> - Demonstrate a self-contained nuclear magnetic resonance gyroscope with ARW < 5e-4deg/rt(hr) and bias stability <1e-4deg/hr in a 20cc package. - Demonstrate an atom interferometer gyroscope with ARW < 5e-4deg/rt(hr) and bias stability <1e-4deg/hr in <150cc (approximately smartphone sized). - Demonstrate whole angle operation in a 3D microgyroscope. - Demonstrate tactical-grade performance of a single-chip MEMS inertial measurement unit.			
Accomplishments/Planned Programs Subtotals		13.363	2.200
C. Other Program Funding Summary (\$ in Millions)			
N/A			
Remarks			
D. Acquisition Strategy			
N/A			
E. Performance Metrics			
Specific programmatic performance metrics are listed above in the program accomplishments and plans section.			

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>						Project (Number/Name) MT-12 / <i>MEMS AND INTEGRATED MICROSYSTEMS TECHNOLOGY</i>			
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Micro-Technology for Positioning, Navigation, and Timing (Micro PN&T)	C/Various	Various : Various	-	12.160		2.002		0.000		-		0.000	0	14.162	0
Subtotal			-	12.160		2.002		0.000		-		0.000	0.000	14.162	0.000
Support (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Government Support	MIPR	Various : Various	-	0.535		0.088		0.000		-		0.000	0	0.623	0
Subtotal			-	0.535		0.088		0.000		-		0.000	0.000	0.623	0.000
Management Services (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Management Support	C/Various	Various : Various	-	0.668		0.110		0.000		-		0.000	0	0.778	0
Subtotal			-	0.668		0.110		0.000		-		0.000	0.000	0.778	0.000
			Prior Years	FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total	Cost To Complete	Total Cost	Target Value of Contract
Project Cost Totals			-	13.363		2.200		0.000		-		0.000	0.000	15.563	0.000
Remarks															

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>	Project (Number/Name) MT-12 / <i>MEMS AND INTEGRATED MICROSYSTEMS TECHNOLOGY</i>

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
<i>Micro-Technology for Positioning, Navigation, and Timing (Micro PN&T)</i>																												
Whole angle 3D microgyroscope demonstration																												
Chip-scale combinatorial atomic navigator (C-SCAN) integrated atomic gyroscope demonstration																												
C-SCAN atomic gyroscope government evaluation																												

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>	Project (Number/Name) MT-12 / <i>MEMS AND INTEGRATED MICROSYSTEMS TECHNOLOGY</i>	

Schedule Details

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
<i>Micro-Technology for Positioning, Navigation, and Timing (Micro PN&T)</i>				
Whole angle 3D microgyroscope demonstration	4	2015	4	2015
Chip-scale combinatorial atomic navigator (C-SCAN) integrated atomic gyroscope demonstration	1	2016	1	2016
C-SCAN atomic gyroscope government evaluation	3	2016	4	2016

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603739E / ADVANCED ELECTRONICS TECHNOLOGIES				Project (Number/Name) MT-15 / MIXED TECHNOLOGY INTEGRATION			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
MT-15: MIXED TECHNOLOGY INTEGRATION	-	67.756	73.821	49.807	-	49.807	74.033	87.960	119.359	165.172	-	-

A. Mission Description and Budget Item Justification

The Mixed Technology Integration project funds advanced development and demonstrations of selected basic and applied electronics research programs. Examples of activities funded in this project include, but are not limited to: (1) component programs that integrate mixed signal (analog and digital; photonic and electronic) or mixed substrate (Gallium Nitride, Gallium Arsenide, Indium Phosphide, or Silicon Germanium with CMOS) technology that will substantially improve the capability of existing components and/or reduce size, weight and power requirements to a level compatible with future warfighter requirements; (2) development and demonstration of brassboard system applications in such areas as laser weaponry or precision navigation and timing to address mid-term battlefield enhancements; and (3) novel technological combinations (i.e., photonics, magnetics, frequency attenuators) that could yield substantial improvement over current systems.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Endurance Description: The Endurance program will develop technology for pod- or internally-mounted lasers to protect a variety of airborne platforms from emerging and legacy electro-optical IR guided surface-to-air missiles. The Endurance system will be a completely self-contained laser weapon system brassboard in an open architecture configuration. The focus of the Endurance effort under MT-15 will be to develop and test integrated subsystems, such as a laser subsystem, a command subsystem, a threat missile warning subsystem, a target acquisition and tracking subsystem, a beam control and director subsystem, an energy storage and electrical power delivery subsystem, a thermal management subsystem a mechanical support framework, subsystem interfaces, and the design, integration, and testing of a form/fit/function brassboard laser countermeasure. This program is an early application of technology developed in the Excalibur program and will transition via industry. Applied research for this program is budgeted in PE 0602702E, Project TT-06. FY 2015 Accomplishments: - Acquired threat devices and/or surrogates in preparation for live fire testing. - Completed the critical design for subsystem integration. - Acquired components for the fabrication of subsystems. FY 2016 Plans: - Complete fabrication and test subsystems. - Integrate, assemble and bench-test the brassboard system.	37.669	23.473	15.307

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>	Project (Number/Name) MT-15 / <i>MIXED TECHNOLOGY INTEGRATION</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Obtain necessary range approvals for live-fire testing.			
FY 2017 Plans:			
- Test the brassboard laser weapon system at outdoor test ranges against a representative set of static and live-fire threat targets. - Assess brassboard system performance in live-fire testing. - Develop a preliminary engineering design for a flight-prototype of a pod-mounted laser weapon system.			
Title: Diverse & Accessible Heterogeneous Integration (DAHI)		15.496	15.335
Description: The scaling of silicon (Si) transistors to ever smaller dimensions has led to dramatic gains in processor performance over the past fifty years. In parallel, integrated circuit (IC) designers for radio frequency (RF) circuits have leveraged the different material properties of compound semiconductor (CS) technologies such as indium phosphide (InP), gallium arsenide (GaAs), gallium nitride (GaN) and silicon-germanium (SiGe) to enable devices that operate at frequencies and powers difficult or impossible to achieve in Silicon. Historically, a designer would have to decide between the high density of Si circuits or the high performance of CS materials. Prior DARPA efforts have demonstrated the ability to achieve near-ideal "mix-and-match" capability for DoD circuit designers with limited demonstrations of the heterogeneous integration of silicon and InP technologies that far exceeded what can be accomplished with one technology alone. Specifically, the Compound Semiconductor Materials On Silicon (COSMOS) program enabled transistors of InP to be freely mixed with silicon complementary metal-oxide semiconductor (CMOS) circuits to obtain the benefits of both technologies (very high speed and very high circuit complexity/density, respectively). The Diverse & Accessible Heterogeneous Integration (DAHI) effort will take this capability to the next level, ultimately offering the seamless co-integration of a variety of semiconductor devices (for example, GaN, InP, GaAs, antimonide based Compound Semiconductors), microelectromechanical (MEMS) sensors and actuators, photonic devices (e.g., lasers, photo-detectors) and thermal management structures. This capability will revolutionize our ability to build true "systems on a chip" (SoCs) and allow dramatic size, weight and volume reductions while enabling higher performance such as power, bandwidth or dynamic range in our electronic systems for electronic warfare, communications and radar. This program has applied research efforts funded in PE 0602716E, Project ELT-01. The Advanced Technology Development part of this program will leverage these complementary efforts to focus on the establishment of an accessible, manufacturable technology for device-level heterogeneous integration of a wide array of materials and devices (including, for example, multiple electronics and MEMS technologies) with complex silicon-enabled (e.g. CMOS) architectures on a common silicon substrate platform. This part of the program is expected to culminate in accessible foundry processes of DAHI technology and demonstrations of advanced microsystems with innovative architectures and designs that leverage heterogeneous integration. By the end of the program, this effort seeks to establish a technologically mature, sustainable DAHI foundry service to be made available (with appropriate computer-aided design support) to a wide variety of DoD laboratory, Federally Funded Research and Development Center (FFRDC), academic and industrial designers.			6.000

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 3		R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>		Project (Number/Name) MT-15 / <i>MIXED TECHNOLOGY INTEGRATION</i>	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
<i>FY 2015 Accomplishments:</i> - Developed a high-yield, high-reliability accessible manufacturing process flow which will be transitioned to a self-sustaining foundry activity providing heterogeneously integrated circuits with four materials/device technologies (silicon (Si) CMOS, InP heterojunction bipolar transistors (HBTs), GaN high-electron-mobility transistors (HEMTs), and high-Q passive devices). - Demonstrated heterogeneously integrated yield test circuits using three device technologies (Si CMOS, InP HBTs, and GaN HEMTs) with measured reliability data. Tracked fabrication process issues and risks and systematically mitigated or eliminated them, resulting in yield structures which meet program metrics. - Demonstrated capability for supporting multi-project wafer runs using the heterogeneous foundry service under development. - Demonstrated a multi-project wafer run including eight external design teams using the DAHI process. Facilitated multi-project wafer foundry through development and support of process design kit and thermal simulation tools. <i>FY 2016 Plans:</i> - Complete development of a high-yield, high-reliability accessible manufacturing process flow which will be transitioned to a self-sustaining foundry activity providing heterogeneously integrated circuits with four materials/device technologies (Si CMOS, InP HBTs, GaN HEMTs, and high-Q passive devices). - Complete demonstration of capability for supporting multi-project wafer runs using the heterogeneous foundry service under development. <i>FY 2017 Plans:</i> - Complete development of a high-yield, high-reliability accessible manufacturing process flow which will be transitioned to a self-sustaining foundry activity providing heterogeneously integrated circuits with four materials/device technologies (Si CMOS, InP HBTs, GaN HEMTs, and high-Q passive devices). Finalize refinements of yield and reliability, and coordinate with self-sustaining foundry activity to ensure successful transition of heterogeneous integration technology. - Complete demonstration of capability for supporting multi-project wafer runs using the heterogeneous foundry service under development. Finalize the development of seamless process design kits and integrated design flows to facilitate the use of the foundry service by external users.					
<i>Title:</i> FLASH - Scaling Fiber Arrays at Near Perfect Beam Quality <i>Description:</i> The goal of the FLASH program is to demonstrate a transportable, ultra-low size, weight, and power (SWaP), packaged laser system by coherently combining the outputs of an array of ultra-lightweight, flight-worthy high-power fiber lasers. The packaged FLASH laser system will project a >30-kW-class beam with near perfect beam quality and very high electrical-to-optical efficiency. The SWaP will be consistent with weight and volume densities needed to support the integration of laser weapons on a broad range of military platforms, including 4th and 5th generation aircraft and UAVs. To accomplish these objectives, FLASH will: (1) greatly reduce the overall size and weight of packaged coherently-combinable high-power fiber laser amplifiers while greatly simplifying the demands they make on support systems such as cabling, cooling lines and			12.591	15.813	12.500

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016		
Appropriation/Budget Activity 0400 / 3		R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>		Project (Number/Name) MT-15 / <i>MIXED TECHNOLOGY INTEGRATION</i>	
B. Accomplishments/Planned Programs (\$ in Millions)			FY 2015	FY 2016	FY 2017
support structures while increasing their efficiency and resistance to shock, vibration and acoustics; and (2) fabricate an array of these ultralight fiber-laser amplifiers and integrate them with advanced battery power, thermal management and coherent-beam combination sub-systems into a transportable, fully packaged, ultra-low SWaP laser system.					
<i>FY 2015 Accomplishments:</i> - Developed and tested a packaged, flight-worthy, coherently-combinable, fiber laser amplifier with an output power, beam-quality, size and weight consistent with system integration on tactical aircraft. - Developed a preliminary design for a >30 kW transportable, packaged laser system including fiber lasers, thermal management, power systems, and beam combination. - Demonstrated, on a lab bench, the coherent combination of over 100 low power fiber lasers into a single beam as a proof-of-concept for the high power system. - Demonstrated, on a lab bench, the coherent combination of 42 output beams of kW-class fiber lasers into a single beam with high efficiency and near-perfect beam quality.					
<i>FY 2016 Plans:</i> - Develop a critical design for a >30 kW transportable, packaged laser system. - Fabricate and/or procure parts and hardware for the >30 kW transportable, packaged laser system. - Assemble and test key subsystems for the >30 kW transportable, packaged laser system. - Begin the integration of key subsystems for a >30 kW transportable, packaged laser system.					
<i>FY 2017 Plans:</i> - Complete integration of the >30 kW transportable, packaged laser system. - Test and demonstrate the >30 kW transportable, packaged laser system.					
<i>Title:</i> Common Heterogeneous integration & IP reuse Strategies (CHIPS)* <i>Description:</i> *Formerly Fast and Big Mixed-Signal Designs (FAB) Developing capabilities to intermix and tightly integrate silicon processes which are currently supported at different scaling nodes and by different vendors is critical to increasing the capabilities of high-performance military microelectronics. For example, Silicon-Germanium (SiGe) Bipolar Complementary Metal-oxide Semiconductor (BiCMOS) processes allow CMOS logic to be integrated with radio frequency (RF) heterojunction bipolar transistors (HBTs), which enables mixed-signal circuits having RF analog capabilities tightly coupled to digital processing. However, the SiGe process flow was developed to integrate to a single CMOS technology node and significant design and engineering effort is required to retarget the flow for a new node. Thus, BiCMOS processes tend to lag behind commercial CMOS by several generations. CHIPS will investigate the potential for a truly process-agnostic integration technology, i.e., one that is inclusive of any current or future circuit fabrication technology such as			-	4.200	5.500

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603739E / ADVANCED ELECTRONICS TECHNOLOGIES	Project (Number/Name) MT-15 / MIXED TECHNOLOGY INTEGRATION		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Gallium Arsenide (GaAs), Gallium Nitride (GaN) and SiGe with a standardized interconnect topology. Such a technology platform will enable the design of individual circuit Intellectual Property (IP) blocks, such as low-noise amplifiers and analog-to-digital converters, with a goal of re-use of the IP across applications. Re-use will allow the DoD to amortize the upfront design cost of these blocks over several designs instead of leveling the burden on a single program. Furthermore, the IP can be designed in the fabrication process best suited for the performance goals and evolve more quickly than larger, more expensive single chip systems-on-a-chip. Through standardization of the interface, CHIPS will enable the DoD to leverage the advancements driven by the global semiconductor market rather than relying on a single on-shore foundry provider or on proprietary circuit designs owned by a handful of traditional prime performers. In the Advanced Technology Development part of this program, focus will be placed on the development of rapid development and insertion of microsystems utilizing III-V semiconductors and other microelectronic technologies with advanced Si CMOS. This program has Applied Research efforts funded in PE 0602716E, Project ELT-01. FY 2016 Plans: - Investigate analog intellectual property (IP) reuse techniques for efficient, rapid fabrication of high-performance RF/microwave circuits. - Develop standardized, high-bandwidth interfaces for chiplet-to-chip interconnection. - Initiate circuit demonstration using intellectual property reuse techniques. FY 2017 Plans: - Conduct system demonstrations using standardized, high-bandwidth interfaces for chiplet-to-chip interconnection of heterogeneous IP. - Initiate circuit demonstrations of chip-to-chip interconnects for heterogeneous IP RF electronic chip stacks.				
Title: Precise Robust Inertial Guidance for Munitions (PRIGM) Description: The DoD relies on GPS for ubiquitous and accurate positioning, navigation, and timing (PNT). With the increased prevalence of intentional GPS jamming, spoofing, and other GPS-denial threats, GPS access is increasingly unavailable in contested theaters and alternative sources of PNT are required. In particular, guided munitions navigation is the most immediate and among the most demanding of GPS-denial challenges, due to the necessity of operating in highly contested theaters and the stringent requirements for minimization of cost, size, weight, and power consumption (CSWaP). The Precise Robust Inertial Guidance for Munitions (PRIGM) program will develop low-CSWaP inertial sensor technology for GPS-free munitions navigation. PRIGM comprises two focus areas: 1) Development of a Navigation-Grade Inertial Measurement Unit (NGIMU) that transitions state-of-the-art MEMS to DoD platforms by 2020; and 2) Research and development of Advanced Inertial MEMS Sensors (AIMS) to achieve gun-hard, high-bandwidth, high dynamic range navigation requirements with the objective of complete autonomy in 2030. PRIGM will advance state-of-the-art MEMS gyros from TRL-3 devices to a TRL-6 transition platform (complete IMU) that		-	13.000	10.500

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>	Project (Number/Name) MT-15 / <i>MIXED TECHNOLOGY INTEGRATION</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
enables Service Labs to perform TRL-7 field demonstrations. PRIGM will exploit recent advances in heterogeneous integration of photonics and CMOS and advanced MEMS technology to realize novel inertial sensors for application in extreme dynamic environments and beyond navigation-grade performance. At present, DoD suffers a trade-space dichotomy between low-CSWaP tactical-grade IMUs, based on MEMS inertial sensors, and relatively high-CSWaP navigation-grade IMUs, based on ring-laser or interferometric fiber-optic gyroscopes (RLG/iFOG). RLG/iFOG is the technology of choice for high-value platforms. However, for the vast majority of platforms (munitions, dismounts, UAVs), CSWaP necessitates the use of lower-performance, MEMS-based IMUs. Under the micro-PNT program, DARPA has developed MEMS gyroscopes with performance rivaling that of navigation-grade interferometric fiber optic gyros (IFOGs), thus exposing a new tradespace for low-CSWaP navigation grade IMUs. The ultimate goal of the program is to develop a complete MEMS-based navigation-grade IMU with an identical mechanical/electronic interface to existing DoD-standard tactical-grade MEMS IMUs, thereby providing a drop-in replacement for existing DoD systems and rapid transition through early insertion demonstrations. This program has basic research efforts funded in PE 0601101E, Project ES-01 and applied research efforts funded in PE 0602716E, Project ELT-01. FY 2016 Plans: - Initiate efforts to demonstrate MEMS inertial sensors that meet all NGIMU performance and environmental requirements. - Design, fabricate, and characterize MEMS gyroscopes meeting stability and repeatability specifications consistent with navigation-grade performance. - Design, fabricate, and characterize MEMS accelerometers meeting stability and repeatability specifications consistent with navigation-grade performance. FY 2017 Plans: - Demonstrate and deliver five MEMS gyroscopes meeting stability and repeatability specifications consistent with navigation-grade performance. - Demonstrate and deliver five MEMS accelerometers meeting stability and repeatability specifications consistent with navigation-grade performance. - Commence development of MEMS-based, navigation-grade, integrated IMU meeting program-defined SWaP and performance metrics, excluding environmental requirements and shock survival.			
Title: Direct SAMpling Digital ReceivER (DISARMER)		2.000	2.000
Description: The goal of the Direct SAMpling Digital ReceivER (DISARMER) program is to produce a hybrid photonic-electronic analog-to-digital converter (ADC) capable of coherently sampling the entire X-band (8-12 GigaHertz (GHz)). Conventional			-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>	Project (Number/Name) MT-15 / <i>MIXED TECHNOLOGY INTEGRATION</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
electronic wideband receivers are limited in dynamic range by both the electronic mixer and the back-end digitizers. By employing an ultra-stable optical clock, the DISARMER program will allow for mixer-less digitization and thereby improve the dynamic range 100x over the state of the art. Such a wide-bandwidth, high-fidelity receiver will have applications in electronic warfare and signals intelligence systems with the potential to drastically reduce the cost, size and weight of these systems. The DISARMER program will design, fabricate, and test a hybrid photonic-electronic ADC packaged in a standard form factor. This involves the integration of electronic and photonic circuits, packaging of a mode-locked laser with ultralow jitter, and delivering a field programmable gate array with the necessary firmware to process the sampled data. This program has applied research efforts funded in PE 0602716E, Project ELT-01. <i>FY 2015 Accomplishments:</i> - Designed, assembled, and tested the prototype track-and-hold chip with 8 channels and optimized optical response to minimize the parasitic capacitance of the circuit. - Demonstrated direct sampling of a 4 GHz-wide bandwidth signal at 7 effective bits of fidelity. <i>FY 2016 Plans:</i> - Demonstrate direct sampling of a 4 GHz-wide bandwidth signal at 10 effective bits of fidelity. - Test system performance across both baseband and the entire X-band (8-12 GHz).			
Accomplishments/Planned Programs Subtotals		67.756	73.821
C. Other Program Funding Summary (\$ in Millions)			
N/A			
Remarks			
D. Acquisition Strategy			
N/A			
E. Performance Metrics			
Specific programmatic performance metrics are listed above in the program accomplishments and plans section.			

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603739E / ADVANCED ELECTRONICS TECHNOLOGIES				Project (Number/Name) MT-15 / MIXED TECHNOLOGY INTEGRATION					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Endurance	C/CPFF	NorthropGrumman : CA	-	18.920	Sep 2015	10.742		7.063		-		7.063	Continuing	Continuing	Continuing
Endurance	C/Various	Various : Various	-	12.932		8.534		3.652		-		3.652	Continuing	Continuing	Continuing
Diverse & Accessible Heterogeneous Integration (DAHI)	C/CPFF	NorthropGrumman : CA	-	11.004	May 2015	5.910		0.000		-		0.000	Continuing	Continuing	Continuing
Diverse & Accessible Heterogeneous Integration (DAHI)	C/Various	Various : Various	-	3.097		8.045		5.185		-		5.185	Continuing	Continuing	Continuing
FLASH - Scaling Fiber Arrays at Near Perfect Beam Quality	C/Various	Various : Various	-	11.568		14.280		11.375		-		11.375	Continuing	Continuing	Continuing
Direct SAMpling Digital ReceivER (DISARMER)	C/Various	Various : Various	-	1.820		1.820		0.000		-		0.000	Continuing	Continuing	Continuing
Common Heterogeneous integration & IP reuse Strategies (CHIPS)	C/TBD	Various : Various	-	0.000		3.672		4.755		-		4.755	Continuing	Continuing	Continuing
Precise Robust Inertial Guidance for Munitions (PRIGM)	C/TBD	Various : Various	-	0.000		11.830		9.555		-		9.555	Continuing	Continuing	Continuing
Subtotal			-	59.341		64.833		41.585		-		41.585	-	-	-
Support (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Government Support	MIPR	Various : Various	-	2.655		3.083		2.242		-		2.242	Continuing	Continuing	Continuing
Subtotal			-	2.655		3.083		2.242		-		2.242	-	-	-

UNCLASSIFIED

Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016		
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>				Project (Number/Name) MT-15 / <i>MIXED TECHNOLOGY INTEGRATION</i>				

Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Endurance Testing	C/Various	Various : Various	-	2.427		2.084		3.214		-		3.214	Continuing	Continuing	Continuing
Subtotal			-	2.427		2.084		3.214		-		3.214	-	-	-

Management Services (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Management Support	C/Various	Various : Various	-	3.333		3.821		2.766		-		2.766	Continuing	Continuing	Continuing
Subtotal			-	3.333		3.821		2.766		-		2.766	-	-	-

			Prior Years	FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total	Cost To Complete	Total Cost	Target Value of Contract
Project Cost Totals			-	67.756		73.821		49.807		-		49.807	-	-	-

Remarks

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency

Date: February 2016

Appropriation/Budget Activity

0400 / 3

R-1 Program Element (Number/Name)

PE 0603739E / ADVANCED
ELECTRONICS TECHNOLOGIES

Project (Number/Name)

MT-15 / MIXED TECHNOLOGY
INTEGRATION

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Endurance																												
System Integration Critical Design Review				■																								
Fabricate and Test Subsystem							■																					
Integrated System Initial Laboratory Test											■																	
Live Fire Range Test												■																
Diverse & Accessible Heterogeneous Integration (DAHI)																												
HI Complex Circuit Design		■	■																									
HI Complex Circuit Fabrication and Test				■	■	■	■																					
HI Complex Circuit Iteration Design					■	■	■																					
HI Complex Circuit Iteration Fabrication and Test							■	■	■	■																		
FLASH - Scaling Fiber Arrays at Near Perfect Beam Quality																												
Compact Laser Preliminary Design Review				■																								
Compact Laser Critical Design Review						■																						
Compact Laser Amplifier Prototype								■																				
Integrated Laser System Initial Test											■																	
Integrated Laser System Final Demonstration												■																
Direct SAMpling Digital ReceivER (DISARMER)																												
Full System Demonstration			■																									
Integration of Sub-Modules			■	■	■	■	■																					
Final System Demonstration								■																				
Common Heterogeneous integration & IP reuse Strategies (CHIPS)																												

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>	Project (Number/Name) MT-15 / <i>MIXED TECHNOLOGY INTEGRATION</i>

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Program Initiation																												
Phase 1 Contract Awards																												
Standard Interface Design Review																												
Heterogeneous Chip Modular Design Review																												
<i>Precise Robust Inertial Guidance for Munitions (PRIGM)</i>																												
Program Initiation																												
Government Evaluation of Inertial Sensors																												
Phase 1 to 2 Transition Decision																												

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603739E / <i>ADVANCED ELECTRONICS TECHNOLOGIES</i>	Project (Number/Name) MT-15 / <i>MIXED TECHNOLOGY INTEGRATION</i>

Schedule Details

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
<i>Endurance</i>				
System Integration Critical Design Review	4	2015	4	2015
Fabricate and Test Subsystem	3	2016	3	2016
Integrated System Initial Laboratory Test	2	2017	2	2017
Live Fire Range Test	4	2017	4	2017
<i>Diverse & Accessible Heterogeneous Integration (DAHI)</i>				
HI Complex Circuit Design	2	2015	3	2015
HI Complex Circuit Fabrication and Test	4	2015	3	2016
HI Complex Circuit Iteration Design	1	2016	3	2016
HI Complex Circuit Iteration Fabrication and Test	3	2016	2	2017
<i>FLASH - Scaling Fiber Arrays at Near Perfect Beam Quality</i>				
Compact Laser Preliminary Design Review	4	2015	4	2015
Compact Laser Critical Design Review	2	2016	2	2016
Compact Laser Amplifier Prototype	4	2016	4	2016
Integrated Laser System Initial Test	2	2017	2	2017
Integrated Laser System Final Demonstration	4	2017	4	2017
<i>Direct SAMpling Digital ReceivER (DISARMER)</i>				
Full System Demonstration	3	2015	3	2015
Integration of Sub-Modules	3	2015	3	2016
Final System Demonstration	4	2016	4	2016
<i>Common Heterogeneous integration & IP reuse Strategies (CHIPS)</i>				
Program Initiation	1	2016	1	2016

UNCLASSIFIED

Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603739E / ADVANCED ELECTRONICS TECHNOLOGIES	Project (Number/Name) MT-15 / MIXED TECHNOLOGY INTEGRATION		
	Start		End	
Events by Sub Project	Quarter	Year	Quarter	Year
Phase 1 Contract Awards	3	2016	3	2016
Standard Interface Design Review	2	2017	2	2017
Heterogeneous Chip Modular Design Review	4	2017	4	2017
Precise Robust Inertial Guidance for Munitions (PRIGM)				
Program Initiation	1	2016	1	2016
Government Evaluation of Inertial Sensors	3	2016	3	2016
Phase 1 to 2 Transition Decision	3	2017	3	2017

UNCLASSIFIED

Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>	R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>

COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	229.945	201.335	155.081	-	155.081	185.554	174.104	163.853	164.183	-	-
CCC-02: <i>INFORMATION INTEGRATION SYSTEMS</i>	-	124.497	102.415	93.781	-	93.781	129.204	123.909	142.233	152.183	-	-
CCC-04: <i>SECURE INFORMATION AND NETWORK SYSTEMS</i>	-	2.450	0.000	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-
CCC-06: <i>COMMAND, CONTROL AND COMMUNICATION SYSTEMS</i>	-	102.998	98.920	61.300	-	61.300	56.350	50.195	21.620	12.000	-	-

A. Mission Description and Budget Item Justification

The Command, Control and Communications Systems program element is budgeted in the Advanced Technology Development Budget Activity because its purpose is to demonstrate and evaluate advanced information systems research and development concepts.

The goal of the Information Integration Systems project is to develop and demonstrate technologies that will provide effective communications to U.S. forces. The success of military operations depends on timely, reliable, secure, and synchronized dissemination of command and control and relevant situational awareness information to every military echelon. While wired communications and networks are fairly well developed, providing assured high-bandwidth mobile wireless capabilities that match or exceed commercial wired infrastructure is needed to meet the demands of military users. Approaches to this goal include developing technologies in these areas:

- High-Capacity Links technologies - enables greater back-haul capability.
- Advanced Networking technologies - supports resilience, adaptability, and scalability.
- Low Probability of Detection and Anti-Jam (LPD/AJ) technologies - provides assured communications in a very high-threat environments.
- Novel Radio Frequency and Spectral Sensing (RF/SS) - supports efficient spectrum management in congested environments and detection of electromagnetic threats.

The Secure Information and Network Systems project developed and demonstrated computer and network technologies and systems suitable for use in military networks, U.S. government enterprise networks, critical infrastructure, and embedded computing systems. The project developed, integrated, and tested technologies for re-using software components.

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS SYST...*

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 1 of 24

R-1 Line #56

Volume 1 - 241

UNCLASSIFIED

Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>	R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	239.265	201.335	122.646	-	122.646
Current President's Budget	229.945	201.335	155.081	-	155.081
Total Adjustments	-9.320	0.000	32.435	-	32.435
• Congressional General Reductions	0.000	0.000			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	-2.033	0.000			
• SBIR/STTR Transfer	-7.287	0.000			
• TotalOtherAdjustments	-	-	32.435	-	32.435

Change Summary Explanation

FY 2015: Decrease reflects reprogrammings and the SBIR/STTR transfer.

FY 2016: N/A

FY 2017: Increase reflects expansion of Project CCC-06 programs.

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603760E / COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS				Project (Number/Name) CCC-02 / INFORMATION INTEGRATION SYSTEMS			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
CCC-02: INFORMATION INTEGRATION SYSTEMS	-	124.497	102.415	93.781	-	93.781	129.204	123.909	142.233	152.183	-	-

A. Mission Description and Budget Item Justification

The success of military operations depends on timely, reliable, secure, and synchronized dissemination of command and control and relevant situational awareness information to every military echelon. While wired communications and networks are fairly well developed, providing assured high-bandwidth mobile wireless capabilities that match or exceed commercial wired infrastructure is needed to meet the demands of military users. The goal of the Information Integration Systems project is to develop and demonstrate technologies that will provide effective communications to U.S. forces. Approaches to this goal include developing technologies in these areas:

- High-Capacity Links technologies - enables greater back-haul capability.
- Advanced Networking technologies - supports resilience, adaptability, and scalability.
- Low Probability of Detection and Anti-Jam (LPD/AJ) technologies - provides assured communications in very high-threat environments.
- Novel Radio Frequency and Spectral Sensing (RF/SS) - supports efficient spectrum management in congested environments and detection of electromagnetic threats.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: 100 Gb/s RF Backbone	13.200	21.750	15.638
Description: The proliferation of video, voice, chat, and other important data-streams on the battlefield is driving a need for higher capacity, reliable, assured, and all-weather communications that are deployable on a wide range of air, ground, and maritime platforms. The goal of this High-Capacity Links technologies program is to demonstrate a 100 Gigabit-per-second (Gb/s) radio frequency (RF) backbone that will meet the anticipated mid-term (within 3-10 years) wireless networking requirements of deployed military forces. DARPA's hybrid Free Space Optical RF Communications Adjunct (ORCA) system has broken the 10 Gb/s wireless network boundary using free-space optical links, but all-weather Ku band components are currently limited to much less than 1Gb/s capacity. Furthermore, the hybrid optical/RF system exhibits size, weight, and power (SWaP) consumption characteristics that preclude deployment on many SWaP-limited platforms. Moving to a millimeter-wave (mmW) solution will provide high capacity and all-weather resiliency, but presents technical challenges that include the generation of higher-order waveforms (beyond common data link), efficient power transmission, high-speed routing, and low-noise receivers. This program seeks to develop the constituent subsystems (waveform generation, efficient power amplifiers, and receivers) and spatial multiplexing architectures to construct an all-weather mmW 100 Gb/s backbone at half the SWaP consumption of the current ORCA system. The 100 Gb/s RF Backbone program is intended for transition to multiple Services.			
FY 2015 Accomplishments: - Built and evaluated modulators capable of generating higher-order waveforms and demodulators capable of digitizing the higher-order waveforms.			

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS*
SYST...

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 3 of 24

R-1 Line #56

Volume 1 - 243

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS	Project (Number/Name) CCC-02 / INFORMATION INTEGRATION SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Evaluated higher-order modulation approaches at mmW frequencies in field demonstrations up to tactically relevant distances. - Evaluated hardware and software capable of spatially multiplexing and de-multiplexing multiple mmW signals. - Evaluated mmW spatial multiplexing approaches to distances at or beyond the Rayleigh Range. - Commenced design and development of an integrated prototype system that includes both higher-order modulation and spatial multiplexing. FY 2016 Plans: - Continue to reduce the size, weight, and power of the system components to metrics consistent with high altitude, long endurance aerial platforms. - Conduct laboratory tests of merged higher-order modulation and spatial multiplexing technologies. - Initiate prototype performance evaluation planning for mountain-to-ground tests at a Government test range. - Conduct initial prototype testing using multiple system configurations to characterize initial system performance. FY 2017 Plans: - Conduct multiple field tests of the prototype hardware at a Government test range. - Integrate prototype onto test aircraft and conduct air-to-ground testing at a Government test range. - Transition the 100 Gb/s RF Backbone system to multiple Services.				
Title: Spectrum Efficiency and Access Description: Current Presidential Initiatives, FCC Broadband Task Force, and Congressional legislation are working to transition large swaths of spectrum (up to 500 MHz) from Federal (DoD is the primary contributor) to civilian use for broadband telecommunications. The DoD will need more highly integrated and networked data/sensor capacity over the next decades and will therefore need new technology that requires less spectrum to operate. The objective of the Spectrum Efficiency and Access program is to investigate improvements in spectral reuse, such as spectrum sharing of sensor/radar bands. The program will leverage technical trends in cooperative sharing to exploit radar anti-jam and interference mitigation technologies that could enable spectrum sharing by allowing overlay of communications within the same spectral footprint. The approach will include exploring real-time control data links between radars and communications systems, and developing the advanced waveforms and components to enable radars and communication networks to operate in close proximity. The ultimate goal is to turn the DoD spectrum loss into a net gain of up to hundreds of MHz in capacity. Technology from this program will be made available to the DoD. FY 2015 Accomplishments: - Modeled and assessed multiple mechanisms for spatial and temporal spectrum sharing between radars and communications networks.		17.462	16.990	15.752

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS SYST...*

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 4 of 24

R-1 Line #56

Volume 1 - 244

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS	Project (Number/Name) CCC-02 / INFORMATION INTEGRATION SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Developed and assessed a baseline set of strategies to defend military systems against threats created by sharing spectrum information between military radars and commercial communications systems. - Developed concepts for a control system to manage mechanisms for spectrum sharing between radars and communication systems. - Demonstrated technologies for signal separation between radar and communications systems operating at the same time, place, and frequency. - Developed concepts and approaches for a joint system design between military radar and military communications systems operating in a shared spectrum allocation that improves overall performance in electronic countermeasure operating environments. FY 2016 Plans: - Model and assess methods for automatically mitigating interfering transmissions caused by malfunctioning or misconfigured communications devices. - Develop and assess updated strategies to defend military systems against threats created by sharing spectrum information between military radars and commercial communications systems. - Develop baseline version of control system to manage spectrum sharing mechanisms. - Conduct laboratory demonstrations of spectrum sharing among conforming radar and military and commercial communications systems that incorporates multiple sharing mechanisms. - Perform initial vulnerability assessment of the spectrum sharing control system and sharing mechanisms through simulated attacks. - Model and assess performance of jointly designed military radar and military communications systems operating in a shared spectrum allocation in electronic countermeasure operating environments. FY 2017 Plans: - Develop improved version of control system to manage spectrum sharing mechanisms. - Modify military and commercial radio and communications systems to support spectrum sharing mechanisms. - Conduct field demonstrations of spectrum sharing among conforming radar and communications systems that incorporates multiple sharing mechanisms. - Reassess vulnerability of the spectrum sharing control system and sharing mechanisms through simulated attacks. - Develop methods for automatically mitigating interfering transmissions caused by malfunctioning or misconfigured communications devices and assess through simulations.				
Title: Advanced RF Mapping		17.705	17.125	11.866
Description: One of the key advantages on the battlefield is the ability to actively sense and manipulate the radio frequency (RF) environment, enabling reliable and assured communications, as well as effectively mapping and manipulating the adversary's				

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SYST...

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 5 of 24

R-1 Line #56

Volume 1 - 245

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>	Project (Number/Name) CCC-02 / <i>INFORMATION INTEGRATION SYSTEMS</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
communications in ways that defy their situational awareness, understanding, or response. Current approaches are emitter-based, with the signal processing techniques focused on array and time-based processing for each emitter. As the RF environment becomes more complex and cluttered, the number of collection assets and the required level of signal processing inhibits our capability to pervasively sense and manipulate at the precision (time, frequency, and space) required for effective action. To address these Radio Frequency and Spectral Sensing (RF/SS) challenges, the Advanced RF Mapping program will develop and demonstrate new concepts for sensing and manipulating the RF environment based on distributed rather than centralized collection. This approach will take advantage of the proliferation of RF devices, such as radios and cell phones, on the battlefield. To leverage these existing devices effectively, the program will develop new algorithms that can map the RF environment with minimal communication load between devices. It will also develop approaches to exploit our precise knowledge of the RF environment and the distributed proximity of RF devices to provide reliable and assured communications for our warfighter as well as to infiltrate or negate our adversaries' communications networks. Building upon technologies investigated within other programs within this project, the Advanced RF Mapping program will enable both offensive and defensive operations in complex RF environments. Advanced RF Mapping technology is planned to transition to the Services. FY 2015 Accomplishments: - Carried out field experiments that demonstrated use of currently deployed tactical radios as sensors within a heterogeneous RF mapping network. - Developed a software layer that simplifies addition of new capabilities to the heterogeneous RF mapping network after it has been fielded. - Demonstrated improved battlefield spectrum planning and spectrum management operations through feedback of spectrum utilization information from RF sensors. - Developed a command and control system for optimizing use of devices as RF sensors in a changing operational environment. - Developed and demonstrated geo-location capability of RF emitters using the heterogeneous RF mapping network. FY 2016 Plans: - Conduct RF Mapping tactical demonstrations. - Develop a baseline sensor management user interface and command and control software layer to enable mission planners to task RF devices and configure the RF mapping system. - Develop a baseline user interface for presenting RF mapping information to tactical units. - Develop software for interconnecting the RF mapping capability with other tactical Electronic Warfare (EW) systems enabling cueing and results sharing. - Develop interface control documentation (ICD) that permits vendors to independently integrate third party RF devices and applications for use as additional RF Mapping sensors.			

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Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 6 of 24

R-1 Line #56

Volume 1 - 246

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>	Project (Number/Name) CCC-02 / <i>INFORMATION INTEGRATION SYSTEMS</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Develop software for storing RF maps and querying the stored data for both tactical use and post-mission analysis. FY 2017 Plans: - Enhance the baseline sensor management and RF Mapping user interfaces for the Services. - Develop final Command and Control (C2) software configurations to integrate RF Mapping sensors into existing Service architectures, to enhance RF sensing capacity. - Continue to participate in Service exercises to demonstrate the system's ability to provide RF sensing and manipulation and inform new tactics, techniques and procedures.			
Title: Communication in Contested Environments (C2E) Description: Building upon the technologies explored and developed under the Computational Leverage Against Surveillance Systems (CLASS) program budgeted in this PE/Project, the Communication in Contested Environments (C2E) program will seek to address communications problems anticipated in networked airborne systems in the mid-21st century. Expected growth in sensor systems, unmanned systems, and internetworked weapons systems will strain the size of networks that our current communications technology can support in the contested environment. As adversary capabilities advance, the DoD will need new techniques to quickly and efficiently accommodate better networking and improved communications capabilities, specifically communications systems with higher capacity, lower latency, greater jamming resistance, and reduced detectability. As part of Advanced Networking technologies efforts, the C2E program addresses these needs with a three-pronged approach: first, to develop heterogeneous networking capabilities and advanced communication technology for airborne systems. Low Probability of Detection (LPD), Anti-Jam (AJ), low latency, and high capacity communication protocols will be developed. Second, to create a government controlled and maintained reference architecture for communications systems that draws from commercial communication architectures. The defense contractor community can build specific communications systems based upon this reference architecture. Finally, C2E will create a government controlled development environment to allow rapid refresh of communications technology and allow third party native application and waveform developers to contribute their own communications technologies. Technologies from this program are planned to transition to the Services. FY 2015 Accomplishments: - Designed, built, and tested the RF Transceiver and Digital waveform processor circuit card assemblies leveraging technology from the DARPA CLASS program. - Designed, built, and tested a communications reference hardware system to support L-band and microwave communications. - Decomposed waveform implementations into re-usable processing elements and compiled representative waveforms for the reference hardware, including initial design for an application-specific integrated circuit (ASIC). - Tested infrastructure networking code on the reference system and evaluated pervasive networking performance.		18.000	9.263

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS*
SYST...

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 7 of 24

R-1 Line #56

Volume 1 - 247

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS	Project (Number/Name) CCC-02 / INFORMATION INTEGRATION SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Deployed the first instantiation of the software development environment for streamlined creation of C2E compliant waveforms and applications. FY 2016 Plans: - Complete development of advanced network processing functions for implementation in an ASIC. - Finalize and integrate LPD/AJ capabilities. - Release updated version of the combined software architecture, development environment and tool set, verification environment, and repository. - Demonstrate Heterogeneous Networking LPD/AJ features, and implement an initial prototype of the C2E reference design on a small form factor radio. - Finalize development of the C2E waveforms and demonstrate performance through laboratory testing. - Demonstrate airborne tactical network waveform interoperability on the C2E reference architecture. - Enhance the software development environment to improve functionality and ease of use. FY 2017 Plans: - Finalize verification testing and system integration of the C2E ASIC. - Complete development of the C2E ASIC operating system, hardware drivers, and encoder drivers. - Complete development and testing of the small form factor radio with integrated C2E ASIC. - Demonstrate legacy waveform interoperability on the small form factor radio.				
Title: Communications Module - Millimeter-wave (COMMO-MMW) Description: The Communications Module - Millimeter-wave (COMMO-MMW) program will develop a compact, scalable, millimeter wave (mm-wave) active electronically scanned array (AESA) module to enable high-performance communications links. The module will focus on low cost connectivity of weapons platforms and systems. The cost will be reduced through exploitation of mass manufacturing techniques at the chip scale and a reduction in size of the system which will aid in retrofitting into existing platforms. The COMMO-MMW module will operate in the high frequency portion of the electromagnetic spectrum to take advantage of reduced competition for bandwidth compared to the increasingly congested bands at lower frequencies. By leveraging mass manufacturing processes to reduce module cost, and new advances in compound semiconductors to enhance system performance, the COMMO-MMW program will realize affordable mm-wave communications that can be made ubiquitous across the domains of modern warfare. Additionally, mm-wave operation offers the potential for extremely high data rate communications links that are intrinsically jam resistant and low probability of detection due to narrow beamwidths and atmospheric propagation characteristics at these frequencies. The lack of commercial component technology in the mm-wave band will further increase the military advantage gained by this capability. This program will develop the critical compound semiconductor devices and circuits for high performance, high power efficiency mm-wave front end electronics, and will apply 3-D and/or heterogeneous integration approaches to build a compact, scalable, mm-wave AESA module. COMMO-MMW not only will		-	7.000	22.762

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS*
SYST...

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 8 of 24

R-1 Line #56

Volume 1 - 248

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>	Project (Number/Name) CCC-02 / <i>INFORMATION INTEGRATION SYSTEMS</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
revolutionize Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) capability but also make it possible and affordable to retrofit existing military systems and extend high performance communications link capability to smaller platforms. Technologies developed under this program will transition to the Services and will provide the capability of "fiber-like" connectivity rates in infrastructure free environments. FY 2016 Plans: - Analyze and design a compact, scalable, mm-wave AESA module supporting a communication demonstration system for long-range power-constrained missions. - Define specifications for the critical components of a 4 x 4 element AESA. - Develop and demonstrate integration approaches for a compact, scalable, mm-wave AESA module with high output power and high power-added efficiency. FY 2017 Plans: - Develop and demonstrate mm-wave devices and circuits to be integrated for transmitter and receiver array demonstration. - Develop a system integration and test plan for the 4x4 element AESA system. - Develop and demonstrate a low-bandwidth communications link based on the COMMO-MMW 4x4 element arrays.			
Title: Dynamic Network Adaptation for Mission Optimization (DyNAMO)* Description: *Formerly Self-Optimizing Networks Wireless networks have evolved into complex systems having many configurable parameters/features, including link data rates, power settings, inter-network gateways, and security associations. The optimal settings for these features vary greatly depending on the mission for which the network is deployed and the environment in which it is operating. Currently, the majority of these features are optimized off-line for specific scenarios and assumptions and are pre-set before use in a mission. There is no capability for the settings to adapt if the actual mission or environment differs from the original assumptions used to configure the network. The problem is exacerbated in scenarios in which intelligent adversaries can affect the topology and operation of the network unpredictably and on short timescales. Furthermore, future operations will include multiple, different radios interconnected on the same platform, and those existing networks lack a common standard for interoperability. The Dynamic Network Adaptation for Mission Optimization (DyNAMO) program will develop software that addresses the incompatibilities preventing information sharing across independent airborne networks and develop new approaches to configure and control networks and networks of networks for operation in dynamic and contested environments. The program will address optimization within legacy and future military networks, interactions between networks, and availability of necessary network services to support mission success. Technologies developed under this program will transition to the Services. FY 2016 Plans:		-	5.050
			18.500

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS SYST...*

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 9 of 24

R-1 Line #56

Volume 1 - 249

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS	Project (Number/Name) CCC-02 / INFORMATION INTEGRATION SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Commence development of candidate near-real-time optimization algorithms to improve network reliability and efficiency when affected by advanced threats. - Propose and analyze candidate inter-network coordination and decentralized network services for operation in the presence of a peer adversary. - Commence development of mission-based network architecture control and information delivery mechanisms. - Conduct testing of individual technology developments in an emulation environment. FY 2017 Plans: - Continue development of near-real-time optimization algorithms. - Develop and integrate inter-network coordination and decentralized network services. - Continue development and integration of mission-based network architecture control and information delivery mechanisms. - Conduct system-level emulation test of system with internetwork coordination and mission-based control. - Conduct hardware-in-the-loop test of system with internetwork coordination and mission-based control.				
Title: Wireless Network Defense Description: A highly networked and enabled force increases efficiency, effectiveness, and safety by making relevant information available when it is needed and at the appropriate location (person/platform/system). Accomplishing this depends on providing reliable wireless communications to all U.S. forces, platforms, and devices in all phases of conflict. Based on initial work under this effort, the Spectrum Efficiency and Access program in this PE/Project was created to enable reliable operation of military and commercial communications and radar systems when occupying the same spectrum bands. As part of the Advanced Networks technologies effort, the Wireless Network Defense program increases wireless network capacity and reliability for tactical users, with the ultimate vision of making high quality data services pervasive throughout the DoD. The primary focus is mitigation of advanced threats particular to the security of wireless networks. The program intends to leverage the capabilities of the dynamic network to identify sources of misinformation, whether malicious or due to poor configuration, across the functional components of the complex system, and mitigate the corresponding effects. Technologies developed under this program will transition to the Services. FY 2015 Accomplishments: - Completed integration of candidate algorithms and protocols for protecting networks from, and detecting and reacting to, misinformation attacks in laboratory-based prototype systems. - Created emulation testbed for evaluating performance of network under various network attacks. - Tested resilience of prototype capabilities in a laboratory environment. - Refined protection mechanisms based on test findings and began development of systems for field demonstrations.		18.880	16.500	-

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS SYST...*

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 10 of 24

R-1 Line #56

Volume 1 - 250

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>	Project (Number/Name) CCC-02 / <i>INFORMATION INTEGRATION SYSTEMS</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Quantified the performance impact of network misconfiguration in simulations of networks in contested environments. FY 2016 Plans: - Increase severity of attacks on prototype system and continue to test resilience in laboratory environment. - Complete integration of candidate algorithms and protocols to prepare for field experiments. - Test resilience of prototype capabilities against advanced attacks in a field environment. - Refine protection mechanisms based on test findings and begin development of systems for transition to military tactical radios. - Integrate with military tactical radios and quantify the performance impact through experiments.			
Title: Computational Leverage Against Surveillance Systems (CLASS) Description: Commercial Test and Measurement equipment has advanced greatly with the emergence of sophisticated cellular and wireless local area network technology and can be used to intercept, analyze, and exploit our military communications signals. The Computational Leverage Against Surveillance Systems (CLASS) program worked to expand Low Probability of Detection/Anti-Jam (LPD)/(AJ) technologies, sought new ways to protect our signals from exploitation by increasingly sophisticated adversaries in ways that can be maintained as commercial technology advances. Three different techniques were developed: 1) Waveform Complexity uses advanced communications waveforms that are difficult to recover without knowledge and understanding of the signals itself; 2) Spatial Diversity uses distributed communications devices and the communication environment to disguise and dynamically vary the apparent location of the signal; and 3) Interference Exploitation makes use of the clutter in the signal environment to make it difficult for an adversary to isolate a particular signal. The program's objective was to make modular communications technology that was inexpensive to incorporate in existing and emerging radio systems (< \$100 incremental cost) but pushed adversaries to need more than 1,000x our processing power - supercomputer-level processing power. Another track of the program extended the CLASS technology to provide LPD communications. These techniques drastically reduced the detectability of communications signals beyond current capabilities. Scalable performance allowed LPD techniques to better trade information rate for communications capacity. Technologies from this program will transition to the Services. FY 2015 Accomplishments: - Developed concepts for integrating CLASS technologies with aircraft antennas and communications equipment. - Measured CLASS modem performance processing power, power consumption, and radio waveform interoperability. - Integrated CLASS modular technology with host processor. - Demonstrated CLASS communication capability with and without interference against Army threat intercept surrogates. - Measured CLASS modem transmit power reduction as number of cooperative transmitters was increased from 1 transmitter to multiple transmitters. - Conducted field tests of integrated CLASS system. - Analyzed field test data and compared achieved performance to program metrics.		24.600	-

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS*
SYST...

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 11 of 24

R-1 Line #56

Volume 1 - 251

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>	Project (Number/Name) CCC-02 / <i>INFORMATION INTEGRATION SYSTEMS</i>		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Transitioned CLASS technology to Army and Navy customers.				
Title: Mobile Hotspots Description: Communications requirements have grown exponentially due to the proliferation of high-data rate sensors (full motion video), Unmanned Aerial Vehicles (UAVs), and the emergence of the Soldier/Marine as both an operator and a sensor within military networks. However, limited spectrum availability results in a large disparity between capacity requirement and availability. Supporting the development of Advanced Networks technologies, Mobile Hotspots developed an airborne high capacity data distribution network to interconnect groups of tactical users in a manner conceptually similar to the commercial tiered approach of interconnecting cell towers and wireless hotspots. Mobile Hotspots exploited advances in millimeter-wave technology and airborne networking to develop a self-organizing, 1 Gb/s mobile tactical airborne network formed from highly-directional communications links to interconnect mounted and dismounted warfighters, dispersed tactical operations centers, and intelligence, surveillance and reconnaissance (ISR) assets. Low size, weight, and power (SWaP) designs were integrated with commercial and military communications equipment and mounted on tactical UAVs and ground vehicles to provide network access to mobile users via infrastructure-less hotspots compatible with existing radios. The Mobile Hotspots program will transition to the Army and Marine Corps Expeditionary Forces. FY 2015 Accomplishments: - Evaluated initial capabilities of the Mobile Hotspot prototype network and millimeter-wave tactical airborne network in an initial ground-based field experiment. - Identified and implemented system and subsystem improvements in preparation for final field experimentation and flight test. - Conducted ground testing of integrated air and ground vehicle systems to validate system operation and performance. - Conducted flight tests to evaluate system performance in various air-to-air, air-to-ground, and multi-node networking configurations.		14.650	-	-
Accomplishments/Planned Programs Subtotals		124.497	102.415	93.781
C. Other Program Funding Summary (\$ in Millions) N/A Remarks D. Acquisition Strategy N/A E. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.				

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS*
SYST...

UNCLASSIFIED

Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603760E / COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS				Project (Number/Name) CCC-02 / INFORMATION INTEGRATION SYSTEMS					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
100 Gb/s RF Backbone (100G)	C/Various	Various : Various	-	3.680		5.900		7.700		-		7.700	Continuing	Continuing	Continuing
100 Gb/s RF Backbone (100G)	C/CPFF	NORTHROP GRUMMAN SYSTEMS CORPORATION : CA	-	8.771	Sep 2015	12.607		4.350		-		4.350	Continuing	Continuing	Continuing
Spectrum Efficiency and Access	C/Various	Various : Various	-	10.950		8.942		10.413		-		10.413	Continuing	Continuing	Continuing
Spectrum Efficiency and Access	C/CPFF	LEIDOS,INC. : VA	-	5.353	Oct 2015	6.832		2.820		-		2.820	Continuing	Continuing	Continuing
Advanced RF Mapping	C/Various	Various : Various	-	6.648		6.926		7.273		-		7.273	Continuing	Continuing	Continuing
Advanced RF Mapping	C/CPFF	LOCKHEED MARTIN CORPORATION : VA	-	8.311	Sep 2015	7.918		3.750		-		3.750	Continuing	Continuing	Continuing
Communication in Contested Environments (C2E)	C/Various	Various : Various	-	13.797		13.876		8.051		-		8.051	Continuing	Continuing	Continuing
Communications Module - Millimeter-wave (COMMO-MMW)	C/Various	Various : Various	-	0.000		6.500		13.987		-		13.987	Continuing	Continuing	Continuing
Dynamic Network Adaptation for Mission Optimization (DyNAMO)	C/Various	Various : Various	-	0.000		4.500		16.900		-		16.900	Continuing	Continuing	Continuing
Wireless Network Defense	C/Various	Various : Various	-	14.145		12.193		0.000		-		0.000	0	26.338	0
Computational Leverage Against Surveillance Systems (CLASS)	C/Various	Various : Various	-	18.514		0.000		0.000		-		0.000	0	18.514	0
Mobile Hotspots	C/Various	Various : Various	-	5.674		0.000		0.000		-		0.000	0	5.674	0
Mobile Hotspots	C/CPFF	L-3 COMMUNICATIONS	-	6.200	Nov 2014	0.000		0.000		-		0.000	0	6.200	0

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS*
SYST...

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 13 of 24

R-1 Line #56

Volume 1 - 253

UNCLASSIFIED

Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>						Project (Number/Name) CCC-02 / <i>INFORMATION INTEGRATION SYSTEMS</i>			
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
		CORPORATION : UT													
Subtotal			-	102.043		86.194		75.244		-		75.244	-	-	-
Support (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Government Support	MIPR	Various : Various	-	4.980		4.097		3.751		-		3.751	Continuing	Continuing	Continuing
Subtotal			-	4.980		4.097		3.751		-		3.751	-	-	-
Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
100 Gb/s RF Backbone (100G)	C/Various	Various : Various	-	0.069		0.523		3.150		-		3.150	Continuing	Continuing	Continuing
Advanced RF Mapping	C/Various	Various : Various	-	0.525		1.220		0.329		-		0.329	Continuing	Continuing	Continuing
Communication in Contested Environments (C2E)	SS/FFP	Various : Various	-	3.836		3.810		0.382		-		0.382	Continuing	Continuing	Continuing
Communications Module - Millimeter-wave (COMMO-MMW)	C/Various	Various : Various	-	0.000		0.000		5.636		-		5.636	Continuing	Continuing	Continuing
Dynamic Network Adaptation for Mission Optimization (DyNAMO)	C/Various	Various : Various	-	0.000		0.000		0.600		-		0.600	Continuing	Continuing	Continuing
Wireless Network Defense	C/Various	Various : Various	-	2.385		1.450		0.000		-		0.000	0	3.835	0
Computational Leverage Against Surveillance Systems (CLASS)	SS/FFP	Various : Various	-	2.878		0.000		0.000		-		0.000	0	2.878	0

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS SYST...*

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 14 of 24

R-1 Line #56

Volume 1 - 254

UNCLASSIFIED

Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>	Project (Number/Name) CCC-02 / <i>INFORMATION INTEGRATION SYSTEMS</i>

Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Mobile Hotspots	C/Various	Various : Various	-	1.556		0.000		0.000		-		0.000	0	1.556	0
Subtotal			-	11.249		7.003		10.097		-		10.097	-	-	-

Management Services (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Management Support	C/Various	Various : Various	-	6.225		5.121		4.689		-		4.689	Continuing	Continuing	Continuing
Subtotal			-	6.225		5.121		4.689		-		4.689	-	-	-

			Prior Years	FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total	Cost To Complete	Total Cost	Target Value of Contract
Project Cost Totals			-	124.497		102.415		93.781		-		93.781	-	-	-

Remarks

UNCLASSIFIED

Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency

Date: February 2016

Appropriation/Budget Activity

0400 / 3

R-1 Program Element (Number/Name)

PE 0603760E / *COMMAND, CONTROL
AND COMMUNICATIONS SYSTEMS*

Project (Number/Name)

CCC-02 / *INFORMATION INTEGRATION
SYSTEMS*

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
100 Gb/s RF Backbone																												
System design and technology development / technology demonstrations		■																										
Prototype testing						■																						
Field testing										■																		
System flight testing												■																
Spectrum Efficiency and Access																												
Demonstration of signal separation technologies	■																											
Lab demonstration of spectrum sharing							■																					
Limited field demonstrations											■																	
Advanced RF Mapping																												
Field experiments and demonstration	■																											
Demonstration of geo-location capability				■																								
Tactical demonstration							■																					
Software development & testing							■	■																				
Field demonstrations											■																	
Communication in Contested Environments (C2E)																												
Transceiver and waveform processor circuit card testing		■																										
Infrastructure networking code testing			■																									
Software development environment deployment				■																								
Software architecture development & release						■																						
Integrated system demo												■																

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS
SYST...*

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 16 of 24

R-1 Line #56

Volume 1 - 256

UNCLASSIFIED

Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>	Project (Number/Name) CCC-02 / <i>INFORMATION INTEGRATION SYSTEMS</i>

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Networking demonstration																												
Communications Module- Millimeter-wave (COMMO-MMW)																												
Program initiation																												
COMMO-MMW Sub-Array Integration contract awards																												
Dynamic Network Adaptation for Mission Optimization (DyNAMO)																												
Program initiation																												
Mission based network technology testing																												
System-level emulation test																												
Mission-based network architecture integration																												
Hardware-in-the-loop system testing																												
Wireless Network Defense																												
Algorithm and protocol integration																												
Algorithm and protocol integration testing																												
Computational Leverage Against Surveillance Systems (CLASS)																												
Software/hardware testing																												
Field tests of integrated system																												
Mobile Hotspots																												
Build, integrate, and test / ground tests																												
Flight test and demonstration																												

UNCLASSIFIED

Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>	Project (Number/Name) CCC-02 / <i>INFORMATION INTEGRATION SYSTEMS</i>	

Schedule Details

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
<i>100 Gb/s RF Backbone</i>				
System design and technology development / technology demonstrations	2	2015	2	2015
Prototype testing	2	2016	2	2016
Field testing	2	2017	2	2017
System flight testing	4	2017	4	2017
<i>Spectrum Efficiency and Access</i>				
Demonstration of signal separation technologies	1	2015	1	2015
Lab demonstration of spectrum sharing	3	2016	3	2016
Limited field demonstrations	3	2017	3	2017
<i>Advanced RF Mapping</i>				
Field experiments and demonstration	1	2015	1	2015
Demonstration of geo-location capability	4	2015	4	2015
Tactical demonstration	3	2016	3	2016
Software development & testing	2	2016	4	2016
Field demonstrations	2	2017	2	2017
<i>Communication in Contested Environments (C2E)</i>				
Transceiver and waveform processor circuit card testing	2	2015	2	2015
Infrastructure networking code testing	3	2015	3	2015
Software development environment deployment	4	2015	4	2015
Software architecture development & release	2	2016	2	2016
Integrated system demo	3	2017	3	2017
Networking demonstration	1	2017	1	2017

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS*
SYST...

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 18 of 24

R-1 Line #56

Volume 1 - 258

UNCLASSIFIED

Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>	Project (Number/Name) CCC-02 / <i>INFORMATION INTEGRATION SYSTEMS</i>

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
<i>Communications Module- Millimeter-wave (COMMO-MMW)</i>				
Program initiation	1	2016	4	2016
COMMO-MMW Sub-Array Integration contract awards	3	2017	3	2017
<i>Dynamic Network Adaptation for Mission Optimization (DyNAMO)</i>				
Program initiation	1	2016	4	2016
Mission based network technology testing	3	2016	4	2016
System-level emulation test	1	2017	2	2017
Mission-based network architecture integration	2	2017	4	2017
Hardware-in-the-loop system testing	3	2017	4	2017
<i>Wireless Network Defense</i>				
Algorithm and protocol integration	4	2015	4	2015
Algorithm and protocol integration testing	2	2016	4	2016
<i>Computational Leverage Against Surveillance Systems (CLASS)</i>				
Software/hardware testing	3	2015	3	2015
Field tests of integrated system	4	2015	4	2015
<i>Mobile Hotspots</i>				
Build, integrate, and test / ground tests	3	2015	3	2015
Flight test and demonstration	4	2015	4	2015

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>	Project (Number/Name) CCC-04 / <i>SECURE INFORMATION AND NETWORK SYSTEMS</i>

COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
CCC-04: <i>SECURE INFORMATION AND NETWORK SYSTEMS</i>	-	2.450	0.000	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-

A. Mission Description and Budget Item Justification

Computer and networking technologies have advanced rapidly with profound effect on the DoD and the nation. The Secure Information and Network Systems project developed and demonstrated computer and network technologies and systems suitable for use in military networks, U.S. government enterprise networks, critical infrastructure, and embedded computing systems. The project developed, integrated, and tested technologies for re-using software components.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Rapid Software Development using Binary Components (RAPID)	2.450	-	-
Description: The Rapid Software Development using Binary Components (RAPID) program developed a system to identify and extract software components for reuse in new applications. The DoD has critical applications that must be ported to future operating systems. In many cases, the application source code is no longer available requiring these applications to continue to run on unsecure and outdated operating systems, impacting operations. A companion applied research effort was budgeted in PE 0602303E, Project IT-03. RAPID capabilities are transitioning to the Services.			
FY 2015 Accomplishments: - Transitioned system outputs based on results from technology evaluation exercises. - Deployed prototype systems at transition partner sites to support initial operations.			
Accomplishments/Planned Programs Subtotals	2.450	-	-

C. Other Program Funding Summary (\$ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS*
SYST...

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 20 of 24

R-1 Line #56

Volume 1 - 260

UNCLASSIFIED

Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603760E / COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS				Project (Number/Name) CCC-04 / SECURE INFORMATION AND NETWORK SYSTEMS					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Rapid Software Development using Binary Components (RAPID)	C/Various	Various : Various	-	2.229		0.000		0.000		-		0.000	0	2.229	0
Subtotal			-	2.229		0.000		0.000		-		0.000	0.000	2.229	0.000
Support (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Rapid Software Development using Binary Components (RAPID)	MIPR	Various : Various	-	0.098		0.000		0.000		-		0.000	0	0.098	0
Subtotal			-	0.098		0.000		0.000		-		0.000	0.000	0.098	0.000
Management Services (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Rapid Software Development using Binary Components (RAPID)	C/Various	Various : Various	-	0.123		0.000		0.000		-		0.000	0	0.123	0
Subtotal			-	0.123		0.000		0.000		-		0.000	0.000	0.123	0.000
			Prior Years	FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total	Cost To Complete	Total Cost	Target Value of Contract
Project Cost Totals			-	2.450		0.000		0.000		-		0.000	0.000	2.450	0.000
Remarks															

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS SYST...*

Defense Advanced Research Projects Agency

UNCLASSIFIED

Page 21 of 24

R-1 Line #56

Volume 1 - 261

UNCLASSIFIED

Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603760E / COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS			Project (Number/Name) CCC-04 / SECURE INFORMATION AND NETWORK SYSTEMS				

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
<i>Rapid Software Development using Binary Components (RAPID)</i>																												
Participated in Cyber Flag Activities																												
Installed Pilot Systems at Transition Partner Site																												
Participated in Cyber Guard Activities																												
Participated in Red Flag Activities																												

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>	Project (Number/Name) CCC-04 / <i>SECURE INFORMATION AND NETWORK SYSTEMS</i>	

Schedule Details

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
<i>Rapid Software Development using Binary Components (RAPID)</i>				
Participated in Cyber Flag Activities	1	2015	1	2015
Installed Pilot Systems at Transition Partner Site	2	2015	2	2015
Participated in Cyber Guard Activities	3	2015	3	2015
Participated in Red Flag Activities	4	2015	4	2015

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603760E / <i>COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS</i>				Project (Number/Name) CCC-06 / <i>COMMAND, CONTROL AND COMMUNICATION SYSTEMS</i>			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
CCC-06: <i>COMMAND, CONTROL AND COMMUNICATION SYSTEMS</i>	-	102.998	98.920	61.300	-	61.300	56.350	50.195	21.620	12.000	-	-
A. Mission Description and Budget Item Justification This project funds classified DARPA programs that are reported in accordance with Title 10, United States Code, Section 119(a)(1) in the Special Access Program Annual Report to Congress.												
B. Accomplishments/Planned Programs (\$ in Millions)									FY 2015	FY 2016	FY 2017	
Title: Classified DARPA Program Description: This project funds Classified DARPA Programs. Details of this submission are classified. FY 2015 Accomplishments: Details will be provided under separate cover. FY 2016 Plans: Details will be provided under separate cover. FY 2017 Plans: Details will be provided under separate cover.									102.998	98.920	61.300	
Accomplishments/Planned Programs Subtotals									102.998	98.920	61.300	
C. Other Program Funding Summary (\$ in Millions) N/A Remarks D. Acquisition Strategy N/A E. Performance Metrics Details will be provided under separate cover.												

PE 0603760E: *COMMAND, CONTROL AND COMMUNICATIONS*
 SYST...

UNCLASSIFIED

Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)					R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY							
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	350.323	425.861	428.894	-	428.894	410.027	392.905	368.717	337.668	-	-
NET-01: JOINT WARFARE SYSTEMS	-	45.784	66.219	72.916	-	72.916	111.556	144.765	160.416	202.367	-	-
NET-02: MARITIME SYSTEMS	-	72.980	119.401	138.303	-	138.303	126.321	162.344	145.301	135.301	-	-
NET-06: NETWORK-CENTRIC WARFARE TECHNOLOGY	-	231.559	240.241	217.675	-	217.675	172.150	85.796	63.000	0.000	-	-

A. Mission Description and Budget Item Justification

The Network-Centric Warfare Technology program element is budgeted in the Advanced Technology Development budget activity because it addresses high payoff opportunities to develop and rapidly mature advanced technologies and systems required for today's network-centric warfare concepts. It is imperative for the future of the U.S. forces to operate flawlessly with each other, regardless of which services and systems are involved in any particular mission. The overarching goal of this program element is to enable technologies at all levels, regardless of service component, to operate as one system.

The objective of the Joint Warfare Systems project is to create enabling technologies for seamless joint operations, from strategic planning to tactical and urban operations. Joint Warfare Systems leverage current and emerging network, robotic, and information technology and provide next generation U.S. forces with greatly expanded capability, lethality, and rapid responsiveness. Critical issues facing this project are: (1) U.S. opponents utilizing systems that are flexible, robust, and difficult to neutralize; and (2) U.S. doctrine that limits the use of firepower to lessen the impact of operations on noncombatants. These problems are magnified in urban and semi-urban areas where combatants and civilians are often collocated, and in peacekeeping operations where combatants and civilians are often indistinguishable. Meeting these challenges places a heavy burden on joint war planning. Understanding opponent networks is essential so that creative options can be developed to counter their strategies. Synchronization of air and ground operations to apply force only where needed and with specific effects is required.

The Maritime Systems project will identify, develop and rapidly mature critical advanced technologies and system concepts for the naval forces' role in today's network centric warfare concept. Improvements in communications between and among submarines, surface ships and naval aircraft have allowed these forces to operate seamlessly with each other and with other Service's network centric systems. Naval forces will play an ever-increasing role in network centric warfare because of their forward deployed nature, their unique capability to operate simultaneously in the air, on the sea and under the sea and their versatile ability to provide both rapid strike and project-sustained force. The technologies developed under this project will capitalize on these attributes, improve them and enable them to operate with other network centric forces.

UNCLASSIFIED

Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>	R-1 Program Element (Number/Name) PE 0603766E / <i>NETWORK-CENTRIC WARFARE TECHNOLOGY</i>

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	360.426	452.861	470.582	-	470.582
Current President's Budget	350.323	425.861	428.894	-	428.894
Total Adjustments	-10.103	-27.000	-41.688	-	-41.688
• Congressional General Reductions	0.000	-7.000			
• Congressional Directed Reductions	0.000	-20.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	0.875	0.000			
• SBIR/STTR Transfer	-10.978	0.000			
• TotalOtherAdjustments	-	-	-41.688	-	-41.688

Change Summary Explanation

FY 2015: Decrease reflects reprogrammings offset by the SBIR/STTR transfer.

FY 2016: Decrease reflects congressional reduction.

FY 2017: Decrease reflects the completion of several classified programs.

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY				Project (Number/Name) NET-01 / JOINT WARFARE SYSTEMS			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
NET-01: JOINT WARFARE SYSTEMS	-	45.784	66.219	72.916	-	72.916	111.556	144.765	160.416	202.367	-	-

A. Mission Description and Budget Item Justification

The objective of the Joint Warfare Systems project is to create enabling technologies for seamless joint operations, from strategic planning to tactical and urban operations. Joint Warfare Systems leverage current and emerging network, robotic, and information technology and provide next generation U.S. forces with greatly increased capability, lethality, and rapid responsiveness. Critical issues facing this project are: (1) U.S. opponents using systems that are flexible, robust, and difficult to neutralize; and (2) U.S. doctrine that limits the use of firepower to lessen the impact of operations on noncombatants. These problems are magnified in urban and semi-urban areas where combatants and civilians are often co-located and in peacekeeping operations where combatants and civilians are often indistinguishable. Meeting these challenges places a heavy burden on joint war planning. Understanding opponent networks is essential so that creative options can be developed to counter their strategies. Synchronization of air and ground operations to apply force only where needed and with specific effects is required. This project supports all levels of the force structure including: (1) the strategic/operational level by generating targeting options against opponents' centers of gravity that have complex networked relationships; (2) the tactical/operational level by managing highly automated forces with tight coupling between air and ground platforms; and (3) the focused tactical level by developing platforms and tools, which acquire targets of opportunity and cue network-based analysis of likely enemy operations thus maximizing the effectiveness of ground forces in stability and support operations.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: System of Systems Integration Technology and Experimentation (SoSite) Description: The System of Systems Integration Technology and Experimentation (SoSite) program seeks to implement an architecture framework capable of assessing and demonstrating potential operational benefits of integrating various system capabilities to improve mission success in contested environments. Such assessments would optimize system-level trades of requirements and architectures to properly leverage an integrated set of system characteristics and capabilities. The demonstration assessment metrics will measure individual and combined system performance to further streamline resource allocation to maximize operational impact. In addition, providing a modeling and simulation (M&S) environment to assess complex systems will enable greater utility of emerging system technologies, since they can be assessed in near-real-world simulations without the real-world costs of testing fully integrated systems. The program will also develop system synthesis and integration technologies that enable rapid assimilation of new and off-the-shelf technologies into the system of systems architecture. These technologies will break down current barriers to entry that new technologies face in system of systems using formal methods, compositional reasoning, and automated design space exploration. Technologies from this program will be transitioned to the Services. FY 2015 Accomplishments: - Developed reference objective system of systems architecture.	17.411	36.109	35.681

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-01 / JOINT WARFARE SYSTEMS	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Commenced development of architecture demonstration plan, including range and platform options. - Implemented M&S capabilities for architecture design analysis and validation. - Commenced the development of system of systems synthesis and integration tools and protocols. - Commenced development of engineering tools to validate system of systems architecture designs. - Commenced development of formal verification techniques to validate integration of constituent systems into a system of systems. - Investigated technologies to facilitate multi-level open architecture security. - Explored alternative systems architectures, designs, tools, and protocols for the maritime environment. FY 2016 Plans: - Complete development of architecture demonstration plan, including range and platform options. - Develop a System Integration Laboratory (SIL) to support Government verification and validation of system of systems architectures. - Complete the development of system of systems synthesis and integration tools and protocols. - Complete prototype architecture designs to implement the system of systems concept. - Initiate experimentation in constructive and virtual environments to validate system of systems approach. - Assess in SIL the capability of new engineering tools to validate system of systems architecture designs. - Assess in SIL the capability of new formal verification techniques to validate integration of constituent systems into a system of systems. - Verify prototype of system of systems architectures in M&S environments. - Develop technologies to facilitate multi-level open architecture security M&S. - Identify the most promising alternative systems architectures, designs, tools, and protocols for the maritime environment. FY 2017 Plans: - Prepare detailed live flight experimentation plans establishing system of systems risk reduction test objectives, experiment designs, required test articles and experiment support assets, and analysis plans. - Secure test articles for flight test experiments: manned and unmanned platforms, and experimental mission systems from DARPA and Service Science and Technology programs. - Secure or develop models of test articles to support laboratory and ground checkout prior to live flight. - Secure support assets required for flight test experiments: ranges and range instrumentation, frequency and airspace authorizations, pilots, virtual and constructive simulation facilities. - Conduct virtual integration and laboratory checkout of system of systems architectures using test article models to verify those architectures will satisfy risk reduction experimentation objectives. - Integrate test articles into system of systems architectures and conduct ground checkout prior to live flight.			

UNCLASSIFIED

Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-01 / JOINT WARFARE SYSTEMS	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Conduct experiments of system of systems architectures in live flight, augmented with virtual and constructive simulation of test articles not ready for live flight; analyze experiment outcomes and document accomplishment of risk reduction objectives.			
Title: Resilient Synchronized Planning and Assessment for the Contested Environment (RSPACE)		11.300	18.236
Description: Currently, Command and Control (C2) of air platforms is a highly centralized process operating largely independently across planning domains (intelligence, surveillance, and reconnaissance (ISR), strike, and spectrum management) and is optimized for a permissive environment. To address the challenges faced in today's increasingly contested environments, the Resilient Synchronized Planning and Assessment for the Contested Environment (RSPACE) program will develop tools to enable distribution of planning functions across the C2 hierarchy for resilience (e.g., loss of communications) while synchronizing strike, ISR, and spectrum planning to maximize the contribution of all assets through increased utilization and exploitation of synergies. The program will develop tools supporting a mixed initiative planning approach, maximizing automation according to operator's choice, and enabling human-in-the-loop intervention and modification. During execution, the tools will provide lifecycle tracking of targeting and information needs and support assessment of progress towards achieving the commander's intent. The tools will dynamically respond as directed to ad hoc requests and significant plan deviations via a real-time dynamic replanning capability, and easily adapt to technology refreshes. The RSPACE tools will transition to the Air Force and the Navy.		25.948	
FY 2015 Accomplishments:			
- Developed initial concept of operations (CONOPS) for a distributed, communications-challenged set of capabilities to support an integrated strike, ISR, and spectrum management planning and assessment working in place of a fixed Air Operations Center (AOC). - Developed initial system architecture and software framework for distributed strike, ISR, and spectrum management to include planning, assessment, and dynamic replanning. - Developed initial models and simulation capability for testing, analysis, and validation of a set of distributed planning and assessment components working in a communications-challenged environment. - Commenced development of algorithms and prototypes for distributed planning and assessment components.			
FY 2016 Plans:			
- Complete initial development of algorithms and prototypes for distributed planning and assessment components. - Develop models and simulation capability for testing, analysis, and validation of a distributed system operating in a communications-challenged environment. - Implement the framework designs into a software prototype. - Test and evaluate candidate software frameworks and components. - Commence development of decision support tools for operational planning.			
FY 2017 Plans:			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-01 / JOINT WARFARE SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Develop experiments to highlight the planning and assessment capabilities in both a distributed and communications-challenged environment. - Continue integration efforts with the prototype framework. - Continue development of planning tools that combine planning for strike, reconnaissance and electronic warfare in a distributed environment. - Continue development of assessment capabilities that automatically track plan execution and alert command and control cells when plans are likely to change. - Demonstrate the ability of small, distributed staffs to plan and manage large-scale operations within an established Air Force modeling and simulation environment.				
Title: Retrodirective Arrays for Coherent Transmission (ReACT) Description: Worldwide advancements in signal processing and electronics have decreased the effectiveness of single-platform, power-based Electronic Warfare (EW) as a viable technique in the future. The goal of the Retrodirective Arrays for Coherent Transmission (ReACT) program is to develop and to demonstrate the capability to combine distributed mobile transmitters to provide high-power spatially resolved EW beams at frequencies utilized by adversary communications and radars. ReACT will achieve this capability by synchronizing multiple distributed transmitters to form a much larger effective array than a single platform could support. The key technical challenge is to synchronize distributed and moving transmitters while compensating for platform motion and vibration. Further, the ReACT system must sense the target's emissions and then optimally configure the ReACT transmitters to focus on the area to be jammed, as well as the minimum power required to sufficiently jam the target. The ReACT program builds upon technology developed under the Arrays at Commercial Timescales (ACT) program, which is budgeted in PE 0602716E, Project ELT-01, and will culminate with a flight demonstration of distributed EW beamforming. The ReACT technology is planned to transition to the Air Force and Navy. FY 2016 Plans: - Complete development of algorithms and hardware for coherent beamforming under mobile environments. - Design vibration compensation circuit for feedback control. - Design algorithms that target an adversary by their emissions. - Identify phenomenological barriers (frequency, motion, and vibration) and validate transition opportunities. - Demonstrate system performance over-the-air in mobile ground environments at extended ranges, under operationally representative motion and vibration. - Integrate tracking algorithms for target motion preparing for air-to-ground demonstration of capability. - Begin coordinating program transition with the Navy. FY 2017 Plans: - Design predictive algorithms for broadband channel estimation.		-	11.874	11.287

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-01 / JOINT WARFARE SYSTEMS	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Design control and feedback circuits to track high velocity targets based on target's emissions. - Integrate hardware for a dynamic airborne demonstration on multiple aircraft. - Demonstrate ReACT system and quantify performance against high velocity airborne target. - Continue coordinating program transition with the Navy.			
Title: High Energy Liquid Laser Area Defense System (HELLADS) Description: The goal of the High Energy Liquid Laser Area Defense System (HELLADS) program was to develop a high-energy laser weapon system that provides an order of magnitude reduction in weight compared to previous laser systems. HELLADS enabled high-energy lasers (HELs) to be integrated onto tactical aircraft and significantly increased engagement ranges compared to ground-based systems, in addition to enabling high precision/low collateral damage and rapid engagement of fleeting targets for both offensive and defensive missions. Advancements in beam control and other subsystems that are required for the practical integration of a laser weapon into existing tactical platforms were explored. With the assistance of the Services, the HELLADS program pursued the necessary analysis, coordination, and design activity for a prototype laser weapon system incorporating the HELLADS laser system and the ABC turret into air-, ground-, or sea-based tactical vehicles. The HELLADS 150 kilowatt (kW) class laser will transition to the Air Force. Additional technologies developed under this program will transition to the Services. FY 2015 Accomplishments: - Completed live fire tests against rocket and mortar fly-outs to demonstrate lethal laser power at mission-relevant ranges. - Completed live fire performance tests of laser weapon system against target sets representative of airborne missions, to include targeting of ground vehicles and self-defense against surface-to-air missiles. - Made system available for transition to the Services, and retain as a demonstration and test asset at the Army High Energy Laser System Test Facility (HELSTF).		13.073	-
Title: Robotics Challenge Description: The Robotics Challenge program sought to boost innovation in autonomous systems and expand platform utility through enhanced actuation, energy density, perception, locomotion, agile reconfiguration, and design efficiency. Program thrusts were centered on a progressive regimen of physical problem solving, real-time team oriented tasks, and dynamic adaptation designed to build "machine trust", especially when integrated with humans in a variety of operational environments. The Robotics Challenge program consisted of a series of obstacle course style challenge events that focused on technology solutions to demonstrate and test robot capabilities for disaster response. The program drove advances in power systems, agility and speed, precision in perception tied to platform coordination, dexterity, and impulsive power. Program objectives focused on technologies to expand mobility and extend endurance of unmanned platforms, advanced tactile and manipulation capabilities, and tools for cost effective design, validation, and construction of autonomous technology, and human-robot interaction. The 6.2 portion of this program was budgeted in PE 0602702E, Project TT-04. Anticipated Service users include the Army, Marines, and Special Forces.		4.000	-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-01 / JOINT WARFARE SYSTEMS	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
FY 2015 Accomplishments: - Conducted DARPA Robotics Challenge Finals.			
Accomplishments/Planned Programs Subtotals		45.784	66.219
C. Other Program Funding Summary (\$ in Millions) N/A			
Remarks			
D. Acquisition Strategy N/A			
E. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.			

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY				Project (Number/Name) NET-01 / JOINT WARFARE SYSTEMS					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
High Energy Liquid Laser Area Defense System (HELLADS)	C/Various	Various : Various	-	9.743		0.000		0.000		-		0.000	0	9.743	0
Resilient Synchronized Planning & Assessment for the Contested Environment	C/Various	Various : Various	-	10.187		16.060		22.322		-		22.322	Continuing	Continuing	Continuing
Retrodirective Arrays for Coherent Transmission (ReACT)	C/Various	Various : Various	-	0.000		10.937		9.584		-		9.584	Continuing	Continuing	Continuing
Robotics Challenge	C/Various	Various : Various	-	3.507		0.000		0.000		-		0.000	0	3.507	0
System of Systems Integration Technology and Experimentation (SoSITE)	C/Various	Various : Various	-	13.099		26.035		25.631		-		25.631	Continuing	Continuing	Continuing
Subtotal			-	36.536		53.032		57.537		-		57.537	-	-	-
Support (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Government Support	MIPR	Various : Various	-	1.831		2.649		2.917		-		2.917	Continuing	Continuing	Continuing
Subtotal			-	1.831		2.649		2.917		-		2.917	-	-	-
Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
High Energy Liquid Laser Area Defense System (HELLADS)	MIPR	W04W USA WHITE SANDS MSL RANGE : NM	-	0.535	Oct 2014	0.000		0.000		-		0.000	0	0.535	0

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY				Project (Number/Name) NET-01 / JOINT WARFARE SYSTEMS					
Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Resilient Synchronized Planning & Assessment for the Contested Environment	C/CR	THE MITRE CORPORATION : VA	-	0.850	Mar 2015	1.077		2.491		-		2.491	Continuing	Continuing	Continuing
Robotics Challenge	C/Various	Various : Various	-	0.494		0.000		0.000		-		0.000	0	0.494	0
System of Systems Integration Technology and Experimentation (SoSITE)	C/Various	Various : Various	-	3.249		6.150		6.325		-		6.325	Continuing	Continuing	Continuing
Subtotal			-	5.128		7.227		8.816		-		8.816	-	-	-
Management Services (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Management Support	C/Various	Various : Various	-	2.289		3.311		3.646		-		3.646	Continuing	Continuing	Continuing
Subtotal			-	2.289		3.311		3.646		-		3.646	-	-	-
			Prior Years	FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total	Cost To Complete	Total Cost	Target Value of Contract
Project Cost Totals			-	45.784		66.219		72.916		-		72.916	-	-	-
Remarks															

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016			
Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY					Project (Number/Name) NET-01 / JOINT WARFARE SYSTEMS			

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021							
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4				
System of Systems Integration Technology and Experimentation (SoSITE)																																
System of System Concept Review																																
Open Systems Architecture Enhancement Reviews/Demonstrations																																
Prototype Architecture Design Review																																
Test Readiness Review																																
Air-Air Kill Chain Live, Virtual, Constructive (LVC) Experimentation																																
Resilient Synchronized Planning & Assessment for the Contested Environment (RSPACE)																																
System architecture and software development																																
Test Event #1 - Component & System Test																																
Test Event #2 - Component & System Test																																
Test Event #3 - Component & System Test																																
Demonstration within modeling environment																																
Retrodirective Arrays for Coherent Transmission (ReACT)																																
Vibration/Motion Compensation																																
Hardware and algorithm completion																																
Dynamic Nodes Demonstration																																
Airborne Target Demonstration																																
High Energy Liquid Laser Area Defense System (HELLADS)																																

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency																				Date: February 2016												
Appropriation/Budget Activity 0400 / 3										R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY										Project (Number/Name) NET-01 / JOINT WARFARE SYSTEMS												
					FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
					1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Live fire performance tests of laser weapons system																																
Baseline target engagements																																
Additional lethality testing for Services																																
Robotics Challenge																																
Conducted DARPA Robotics Challenge Finals																																

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-01 / JOINT WARFARE SYSTEMS	

Schedule Details

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
<i>System of Systems Integration Technology and Experimentation (SoSITE)</i>				
System of System Concept Review	1	2015	4	2015
Open Systems Architecture Enhancement Reviews/Demonstrations	1	2015	4	2016
Prototype Architecture Design Review	1	2016	4	2016
Test Readiness Review	2	2017	4	2017
Air-Air Kill Chain Live, Virtual, Constructive (LVC) Experimentation	3	2017	3	2017
<i>Resilient Synchronized Planning & Assessment for the Contested Environment (RSPACE)</i>				
System architecture and software development	2	2015	3	2015
Test Event #1 - Component & System Test	2	2016	2	2016
Test Event #2 - Component & System Test	4	2016	4	2016
Test Event #3 - Component & System Test	2	2017	2	2017
Demonstration within modeling environment	4	2017	4	2017
<i>Retrodirective Arrays for Coherent Transmission (ReACT)</i>				
Vibration/Motion Compensation	2	2016	2	2016
Hardware and algorithm completion	3	2016	3	2016
Dynamic Nodes Demonstration	3	2016	3	2016
Airborne Target Demonstration	2	2017	4	2017
<i>High Energy Liquid Laser Area Defense System (HELLADS)</i>				
Live fire performance tests of laser weapons system	1	2015	1	2015
Baseline target engagements	2	2015	2	2015
Additional lethality testing for Services	2	2015	4	2015

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency				Date: February 2016	
Appropriation/Budget Activity 0400 / 3		R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY		Project (Number/Name) NET-01 / JOINT WARFARE SYSTEMS	
		Start		End	
Events by Sub Project		Quarter	Year	Quarter	Year
Robotics Challenge					
Conducted DARPA Robotics Challenge Finals		3	2015	3	2015

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY				Project (Number/Name) NET-02 / MARITIME SYSTEMS			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
NET-02: MARITIME SYSTEMS	-	72.980	119.401	138.303	-	138.303	126.321	162.344	145.301	135.301	-	-

A. Mission Description and Budget Item Justification

The objective of the Maritime Systems project is to identify, develop, and rapidly mature critical advanced technologies and system concepts for the naval forces' role in today's network centric warfare concept. Improvements in communications between and among submarines, surface ships, and naval aircraft have allowed these forces to operate seamlessly with each other and with other Service's network centric systems. Naval forces will play an ever-increasing role in network centric warfare because of their forward deployed nature, their unique capability to operate simultaneously in the air, on the sea and under the sea, and their versatile ability to provide both rapid strike and project sustained force. The technologies developed under this project will capitalize on these attributes, improve them, and enable them to operate with other network centric forces.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Hydra	24.790	29.363	24.210
Description: The Hydra program will develop and demonstrate advanced capabilities for the undersea deployment and employment of unique payloads. Hydra integrates existing and emerging technologies and the ability to be positioned in the littoral undersea battlespace to create a disruptive capability. The system consists of a modular enclosure with communications, command and control, energy storage, and standard interfaces for payload systems. The modular enclosures are deployed by various means, depending on the need for speed and stealth, and remain deployed until awakened for employment. Hydra will develop critical enabling technologies for energy storage and recharging, communications, command and control, deployment, and autonomous operations. Technologies from this program will transition to the Navy.			
FY 2015 Accomplishments: - Completed concept designs for the modular enclosure and potential payloads. - Began development of a prototype modular enclosure. - Began development of undersea and air vehicle payloads. - Demonstrated enabling technologies and subsystems. - Conducted initial flight test of the air vehicle.			
FY 2016 Plans: - Build and test prototype modular enclosure. - Complete preliminary design review for undersea payload. - Complete component testing on undersea payload technologies. - Complete critical design review for air vehicle payload.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-02 / MARITIME SYSTEMS	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Conduct flight tests of the air vehicle. FY 2017 Plans: - Construct and demonstrate a prototype modular enclosure. - Complete a full air vehicle flight test. - Launch air vehicle from modular enclosure.			
Title: Hybrid Multi Material Rotor Full Scale Demonstration (HyDem) Description: The goal of the Hybrid Multi Material Rotor Full Scale Demonstration (HyDem) program is to dramatically improve U.S. Navy submarine superiority. HyDem will apply breakthroughs in materials and material system technologies, and multi-disciplinary design methods to a Virginia Class Submarine propulsor, a critical component in submarine performance. The U.S. Navy's ability to operate their submarine fleet with improved capability allows for the creation of strategic surprise. Submarines could exploit expanded areas which were previously unattainable for the purpose of submarine warfare, including antisubmarine warfare (ASW), antisurface warfare (ASuW), intelligence, surveillance and reconnaissance (ISR) gathering, strike, Special Forces operations, and strategic deterrence missions. The HyDem program will design, manufacture, and supply the Navy with a novel component for integration into a new construction Virginia Class Submarine. The Navy will evaluate this component in sea trials. It is envisioned that the Navy will integrate this design change into the future development of the Virginia Class and Ohio Replacement Submarines, and back-fit previously constructed Virginia Class Submarines. This program will transition to the Navy. FY 2015 Accomplishments: - Conducted a Preliminary Design Review. - Completed manufacturing drawings and tooling. - Conducted a Critical Design Review. - Incorporated design lessons-learned from large scale vehicle (LSV) testing of scaled unit. - Continued structural building block testing. - Confirmed high-cycle fatigue endurance limit for structural material. - Initiated manufacturing of the full-scale propulsor component to be installed on a Virginia Class submarine. - Conducted a shock test of a large-scale model. FY 2016 Plans: - Complete structural building block testing. - Complete manufacturing of the full-scale propulsor component. - Deliver full-scale propulsor component to the Navy for integration into a Virginia Class submarine. - Assess structural and shock qualification of the propulsor component.		9.982	14.000
			7.500

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-02 / MARITIME SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Provide integration support for the propulsor component. - Complete shock building block testing. - Initiate development of advanced concepts seeking to improve performance and affordability. - Initiate long-term environment exposure monitoring test program. FY 2017 Plans: - Complete shock qualification of propulsor component. - Complete development of advanced concepts. - Transition long-term environmental exposure monitoring program to the Navy.				
Title: Tactical Undersea Network Architecture Description: Systems fighting as a network are vulnerable to a loss of connectivity in a contested environment. This connectivity is important for synchronizing forces, establishing and maintaining situation awareness, and control of remotely operated vehicles and systems. Additionally, undersea systems are challenged to maintain connectivity and must carry their own energy and operate over their design lifetime with little to no maintenance and repair. These factors inhibit their use in collaborative networks and prevent the full exploitation of the potential of undersea systems. By leveraging techniques explored under the Distributed Agile Submarine Hunting (DASH) program budgeted within this PE/Project, the Tactical Undersea Network Architecture program will overcome these limitations by developing the technologies necessary for autonomous, reliable, and secure undersea data transfers; true plug, play, and operating standards; and rapid, cost effective deployment technologies. The program will develop and demonstrate novel technology options and designs to temporarily restore connectivity for existing tactical data networks in contested environments using small diameter optical fiber and buoy relay nodes. The program will focus on innovative system architecture designs, lightweight optical fiber technologies, and rapidly deployable buoy node designs and component technologies. The Tactical Undersea Network Architecture program will emphasize early risk reduction with future scaled at-sea integrated demonstrations of increasing complexity. Program technologies will transition to the Navy. FY 2015 Accomplishments: - Commenced system architecture design trade studies, modeling, and simulation. - Commenced small lightweight optical fiber development and fiber performance testing. - Assessed system deployment options; developed cost model. - Developed system component-level technologies and commenced scaled component-level testing. - Identified key system risks and technology trades. FY 2016 Plans: - Evaluate environmental condition's impact on system performance via modeling and simulation. - Complete system architecture design trade studies and preliminary designs.		13.384	19.500	22.173

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-02 / MARITIME SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Continue fiber performance testing; demonstrate fiber survivability under at-sea conditions. - Conduct system-level performance modeling. - Complete component-level testing. - Commence prototype system design and plan for sea test. FY 2017 Plans: - Complete and evaluate prototype system design and design review. - Commence system fabrication and integration testing. - Continue at-sea system demonstration planning and coordination. - Demonstrate deployment and at-sea operation and survival.				
Title: Blue Wolf Description: Undersea platforms have inherent operational and tactical advantages such as stealth and surprise. Platform drag due to fluid viscosity and platform powering requirements varies with the speed through the water. Platform energy and power density limitations create two distinct operational usage profiles: one for unmanned undersea vehicles (low speed, long endurance) and another for undersea weapons (high speed, short endurance). Designers have historically solved this with hybrid systems such as the Navy's Vertical Launch Anti-Submarine Rocket, or by increasing the size of undersea systems. However, hybrid systems can be vulnerable to air and undersea defensive systems and larger undersea systems can result in significant launch platform modifications. The Blue Wolf program seeks to provide a radically different solution to develop and demonstrate an undersea demonstrator vehicle with endurance and speed capabilities beyond conventional undersea systems within the weight and volume envelopes of current Navy undersea systems. Significant technical challenges to be addressed include: dynamic lift and drag reduction; hybrid energy system development compatible with existing manned platform safety requirements and certification; and system integration and demonstration in at-sea environment. The program will leverage Navy connectivity, autonomy, guidance, navigation, and obstacle avoidance technologies and culminate in a series of at-sea demonstrations and transition to the Navy. FY 2015 Accomplishments: - Commenced platform and module design and technology assessments and system safety and effectiveness modeling. - Established baseline test platform architecture and conducted initial check-out testing. - Developed interface control documentation. - Developed model-based engineering environment for rapid trade analyses. - Conducted design trade studies to refine system architecture. - Conducted system performance modeling and simulation and small scale laboratory trials.		11.500	15.500	11.000

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-02 / MARITIME SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Commenced system design safety certification and system engineering including test planning.				
FY 2016 Plans: - Complete component designs and design reviews. - Commence module development and fabrication. - Commence sub-system hardware and software testing and module integration. - Update system performance models and conduct initial at-sea testing. - Commence subsystem safety certifications and testing.				
FY 2017 Plans: - Complete module fabrication and integration. - Continue system at-sea testing. - Complete module and system safety and certification testing and analyses. - Commence at-sea demonstration planning, training, and support preparations. - Complete system integration and checkouts.				
Title: Positioning System for Deep Ocean Navigation (POSYDON)* Description: *Formerly Long-Range Undersea Navigation The Positioning System for Deep Ocean Navigation (POSYDON) program will provide continuous, Global Positioning System (GPS)-level positioning accuracy to submarines and autonomous undersea vehicles (AUVs) in ocean basins over extended periods of time. Undersea navigation cannot use GPS because the water blocks its signals. At shallower depths, masts can be raised to receive GPS signals, but masts present a detection risk. Typically, the alternative to GPS for undersea navigation has been inertial navigation systems (INS), but INS accuracy can degrade unacceptably over time. Building upon concepts explored under the Distributed Agile Submarine Hunting (DASH) program, budgeted within this PE/Project, and the Upward Falling Payloads program, PE 0602702E, Project TT-03, the POSYDON program will distribute a small number of acoustic sources, analogous to GPS satellites, around the ocean basin. A submarine or AUV will be equipped with an acoustic receiver and appropriate software in order to obtain, maintain, and re-acquire, if lost, an initial location. By transmitting specific acoustic waveforms and developing accurate acoustic propagation models to predict and interpret the complex arrival structure of the acoustic sources, the submarine or AUV can determine its range from each source and thus triangulate its position. Technologies developed under this program will transition to the Navy. FY 2016 Plans: - Design and develop algorithms for accurately predicting acoustic signal propagation paths. - Develop the system concept of operations.		-	18.620	24.570

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-02 / MARITIME SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Conduct at-sea experiments to validate analysis using a single source/receiver pair at basin-scale range to measure signal tracking accuracy and stability as well as signal acquisition techniques. FY 2017 Plans: - Design and develop signal waveforms for transmitters and receivers. - Refine the system concept of operations based on data collections from at-sea experiments. - Update ocean models to support real-time ranging. - Conduct multiple at-sea demonstrations of real-time ranging signals in various environments with noise and interference.				
Title: Mobile Offboard Command, Control and Attack (MOCCA) Description: The Mobile Offboard Command, Control and Attack (MOCCA) program seeks to counter the fourth generation submarine signature quieting technology that has significantly degraded passive anti-submarine warfare (ASW) sonar detection range and targeting performance. The MOCCA program will build on lessons learned under the Distributed Agile Submarine Hunting (DASH) program, budgeted within this PE/Project, to nullify submarine signature reduction trends with active sonar projectors deployed from a mobile unmanned undersea vehicle (UUV) and cooperatively processed with onboard submarine acoustic receive sonar systems. The off-board UUV sonar projector will operate, under positive control, at a significant distance from the cooperative submarine using communication links. The program seeks to achieve breakthrough capability for long-range submarine detection and precision target tracking. The program will develop compact, high output acoustic transducers, novel low probability of intercept/low probability of detection (LPI/LPD) communication signaling, and high energy density sub-systems compatible with deployable UUV packaging constraints. In addition, the MOCCA system will be integrated into submarine onboard sonar and weapons control systems. This program will transition to the Navy. FY 2016 Plans: - Begin preliminary design of hardware and software components. FY 2017 Plans: - Evaluate designs on compact acoustic projectors, UUV energy solutions, LPI/LPD communications link system components. - Develop subsystems including compact high output acoustic projector, UUV energy solutions, LPI/LPD communications link system. - Commence testing to evaluate at-sea performance of UUV mobile sonar demonstrating source level and beam control, LPI/LPD communications waveforms detectability, range performance and data rate, and submarine Bi-static sonar processing algorithms. - Initiate process for approval of temporary system integration into submarine systems for test and evaluation.		-	4.200	16.334
Title: Virtual Acoustic Microphone System (VAMS)		-	5.000	15.958

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-02 / MARITIME SYSTEMS	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
Description: The Virtual Acoustic Microphone System (VAMS) program will develop additional acoustic sensor capabilities for underwater platforms. The VAMS program seeks to develop and demonstrate technologies that enable the laser projection of underwater acoustic sensor arrays with performance comparable to existing arrays. The VAMS approach, however, will allow the array to be adaptively reconfigured, enabling capabilities that are not currently possible with existing technology. Expanding on lessons learned from the Distributed Agile Submarine Hunting (DASH) program, budgeted within this PE/Project, the program will combine reconfigurable laser transmitters with novel signal extraction methods and exploit new and emerging high-speed sensor and processor capabilities. The VAMS system has the potential to be integrated into a number of underwater platforms. The acoustic sensor technology developed under the VAMS program will transition to the Navy. FY 2016 Plans: - Evaluate core enabling technologies, including the application of high-speed sensor technology to increase the sensitivity of laser-based acoustic detection. FY 2017 Plans: - Initiate system design, which will demonstrate the required acoustic capabilities. - Initiate the development of advanced signal processing methods that will enable acoustic information extraction from the laser-based sensor and compensate for motion of the platform.			
Title: Cross Domain Maritime Surveillance and Targeting (CDMaST) Description: The Cross Domain Maritime Surveillance and Targeting (CDMaST) program seeks to identify and implement architectures consisting of novel combinations of manned and unmanned systems to execute long-range kill chains against submarines and ships over large contested maritime areas. By exploiting promising new developments in unmanned platforms, seafloor systems, and emerging long-range weapon systems, the program will develop an advanced, integrated undersea and above sea warfighting capability. Building upon research conducted under the System of Systems Integration Technology and Experimentation (SoSite) program (budgeted in PE 0603766E, Project NET-01), the Cross Domain Maritime Surveillance and Targeting (CDMaST) program will establish an analytical and experimental environment to explore architecture combinations in terms of operational effectiveness as well as engineering feasibility and robustness. The program will leverage enabling technologies needed for command, control, and communication (C3) between physical domains in order to support the architecture constructs. Through experimentation, the program will not only demonstrate integrated system performance, but also develop new tactics that capitalize on features created by the heterogeneous architecture. The Cross Domain Maritime Surveillance and Targeting (CDMaST) program will invest in technologies that will reduce cost, manage complexity, and improve reliability. Technologies from this program will transition to the Navy.		-	4.000
			16.558

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-02 / MARITIME SYSTEMS	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
FY 2016 Plans: - Establish modeling and simulation environment to conduct high fidelity mission-level architecture analysis.			
FY 2017 Plans: - Develop baseline system of systems architecture. - Create concept design for system of systems live, virtual, and constructive test bed environment.			
Title: Distributed Agile Submarine Hunting (DASH) Description: The diesel-electric submarine is an asymmetric threat in terms of its cost and consequential growth in numbers relative to our legacy maritime platforms. In addition, these submarines have trended toward lower acoustic signature levels and have grown in lethality. The Distributed Agile Submarine Hunting (DASH) program intends to reverse the asymmetric advantage of this threat through the development of advanced standoff sensing from unmanned systems. Deep-ocean sonar nodes will be developed to operate at significant depths in open ocean areas to achieve large fields of view to detect submarines overhead. Each deep node is the maritime equivalent of a satellite, and is referred to as a subullite. The significant field of view, along with the advantage of low-noise phenomena at extreme depths, will permit a scalable number of collaborative sensor platforms to detect and track submarines over large areas. At-sea demonstrations have shown that the detection capability is achievable. The program will continue to develop prototype systems that will evolve through additional at-sea testing. These tests will demonstrate the ability to integrate into the Navy's undersea systems responsible for anti-submarine warfare (ASW). The program seeks to achieve breakthrough technology for long-range detection and classification, communications, energy management, sensor and platform integration, and robust semiautonomous processing and control for distributed sensing platforms. This program will transition to the Navy.		13.324	9.218
FY 2015 Accomplishments: - Designed and developed longer duration passive and active sonar nodes. - Conducted extended duration sonar demonstrations at sea against a target. - Demonstrated connectivity from seafloor node to remote shore station. - Integrated distributed communications with Navy systems for data transfer and Command, Control, Communications, Computers, and Intelligence (C4I). - Initiated test planning for passive and active sonar sea test. - Explored alternative concepts of operations and modified architectures of DASH system for other applications. - Initiated data collection experiments in other significant Navy operational areas to characterize DASH performance.			-
FY 2016 Plans: - Conduct at-sea demonstrations of a distributed deep-ocean passive sonar barrier using multiple nodes for extended duration. - Conduct at-sea demonstrations of a mobile active sonar node.			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-02 / MARITIME SYSTEMS	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Perform data-driven signal processing development to improve automated sonar detection algorithms. - Provide analysis and data to support Navy utility assessments and studies to aid in transition. - Complete data collection experiments in other significant Navy operational areas to characterize DASH performance. - Continue to explore alternate techniques for long-range submarine detection and precision target tracking.			
Accomplishments/Planned Programs Subtotals		72.980	119.401
C. Other Program Funding Summary (\$ in Millions)			
N/A			
Remarks			
D. Acquisition Strategy			
N/A			
E. Performance Metrics			
Specific programmatic performance metrics are listed above in the program accomplishments and plans section.			

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY				Project (Number/Name) NET-02 / MARITIME SYSTEMS					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Hydra	C/CPFF	Oceaneering International, Inc. : MD	-	6.474	Jan 2015	0.646		0.000		-		0.000	Continuing	Continuing	Continuing
Hydra	C/CPFF	Raytheon Company : CA	-	8.437	Mar 2015	19.974		12.393		-		12.393	Continuing	Continuing	Continuing
Hydra	C/Various	Various : Various	-	7.647		6.101		5.100		-		5.100	Continuing	Continuing	Continuing
Hybrid Multi Material Rotor Full Scale Demonstration (HyDem)	C/CPFF	Goodrich Corporation : FL	-	6.465	Dec 2014	6.760		2.500		-		2.500	Continuing	Continuing	Continuing
Hybrid Multi Material Rotor Full Scale Demonstration (HyDem)	C/Various	Various : Various	-	2.619		5.980		4.325		-		4.325	Continuing	Continuing	Continuing
Tactical Undersea Network Architecture	C/Various	Various : Various	-	11.449		14.560		18.815		-		18.815	Continuing	Continuing	Continuing
Blue Wolf	C/Various	Various : Various	-	10.465		14.505		9.590		-		9.590	Continuing	Continuing	Continuing
Positioning System for Deep Ocean Navigation (POSYDON)*	C/CPFF	Various : Various	-	0.000		11.903		23.134		-		23.134	Continuing	Continuing	Continuing
Positioning System for Deep Ocean Navigation (POSYDON)*	C/CPFF	THE CHARLES STARK DRAPER LABORATORY INC : MA	-	0.000		5.757		0.000		-		0.000	0	5.757	0
Mobile Offboard Command, Control and Attack (MOCCA)	C/Various	Various : Various	-	0.000		3.430		15.122		-		15.122	Continuing	Continuing	Continuing
Virtual Acoustic Microphone System (VAMS)	C/Various	Various : Various	-	0.000		3.950		11.283		-		11.283	Continuing	Continuing	Continuing
Cross Domain Maritime Surveillance and Targeting (CDMaST)	C/Various	Various : Various	-	0.000		3.310		15.224		-		15.224	Continuing	Continuing	Continuing

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY				Project (Number/Name) NET-02 / MARITIME SYSTEMS					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Distributed Agile Submarine Hunting (DASH)	SS/CPFF	Various : Various	-	10.926		7.290		0.000		-		0.000	0	18.216	0
Subtotal			-	64.482		104.166		117.486		-		117.486	-	-	-
Support (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Government Support	C/Various	Various : Various	-	2.919		4.776		5.532		-		5.532	Continuing	Continuing	Continuing
Subtotal			-	2.919		4.776		5.532		-		5.532	-	-	-
Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Hydra	C/Various	Various : Various	-	0.000		0.000		2.725		-		2.725	Continuing	Continuing	Continuing
Hybrid Multi Material Rotor Full Scale Demonstration (HyDem)	C/Various	Various : Various	-	0.000		0.000		1.750		-		1.750	Continuing	Continuing	Continuing
Tactical Undersea Network Architecture	MIPR	Various : Various	-	0.562		3.195		0.000		-		0.000	0	3.757	0
Positioning System for Deep Ocean Navigation (POSYDON)*	MIPR	Various : Various	-	0.000		0.175		0.650		-		0.650	Continuing	Continuing	Continuing
Mobile Offboard Command, Control and Attack (MOCCA)	C/TBD	Various : Various	-	0.000		0.000		0.200		-		0.200	Continuing	Continuing	Continuing
Virtual Acoustic Microphone System (VAMS)	C/TBD	Various : Various	-	0.000		0.000		3.045		-		3.045	Continuing	Continuing	Continuing

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY				Project (Number/Name) NET-02 / MARITIME SYSTEMS					
Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Distributed Agile Submarine Hunting (DASH)	C/Various	Various : Various	-	1.368		1.118		0.000		-		0.000	0	2.486	0
Subtotal			-	1.930		4.488		8.370		-		8.370	-	-	-
Management Services (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Management Support	C/Various	Various : Various	-	3.649		5.971		6.915		-		6.915	Continuing	Continuing	Continuing
Subtotal			-	3.649		5.971		6.915		-		6.915	-	-	-
			Prior Years	FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total	Cost To Complete	Total Cost	Target Value of Contract
Project Cost Totals			-	72.980		119.401		138.303		-		138.303	-	-	-
Remarks															

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016			
Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY					Project (Number/Name) NET-02 / MARITIME SYSTEMS			

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Hydra																												
Modular Enclosure Preliminary Design Review																												
Air Vehicle Initial Flight Test																												
Test Prototype Modular Enclosure																												
Critical Design Review of Undersea Payload and Air Vehicle Payload																												
Complete a Full Air Vehicle Flight Test																												
Demonstrate Full Undersea Payload Demonstration from the Modular Enclosure																												
Hybrid Multi Material Rotor Full Scale Demonstration (HyDem)																												
Preliminary Design Review																												
Critical Design Review																												
Deliver Full Scale Component to Navy																												
Support Propulsor Integration on VIRGINIA Class Submarine																												
Support Propulsor Testing																												
Tactical Undersea Network Architecture																												
System architecture design studies																												
Preliminary Design Review of system architecture																												
Component Testing																												
Software Design Review (SDR)																												
At-sea demonstration																												
Blue Wolf																												

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency

Date: February 2016

Appropriation/Budget Activity

0400 / 3

R-1 Program Element (Number/Name)

PE 0603766E / NETWORK-CENTRIC
WARFARE TECHNOLOGY

Project (Number/Name)

NET-02 / MARITIME SYSTEMS

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Initial Check-Out Testing																												
Design Safety Certification																												
Sub-System Hardware and Software Testing																												
Module Development and Fabrication																												
System At-Sea Testing																												
Complete System Integration																												
Positioning System for Deep Ocean Navigation (POSYDON)																												
Program Initiation																												
Conduct at-sea data collections																												
Conduct real-time ranging demonstrations																												
Mobile Offboard Command, Control and Attack (MOCCA)																												
Program Initiation																												
Evaluation testing of UUV mobile sonar																												
Virtual Acoustic Microphone Systems (VAMS)																												
Program Initiation																												
System development and design review																												
Cross Domain Maritime Surveillance and Targeting (CDMaST)																												
Program Initiation																												
Concept design for test bed environment																												
Distributed Agile Submarine Hunting (DASH)																												
At sea sonar demonstrations																												
Node Design Validations																												

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency																							Date: February 2016														
Appropriation/Budget Activity 0400 / 3										R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY										Project (Number/Name) NET-02 / MARITIME SYSTEMS																	
										FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
										1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
At sea mobile active sonar demonstrations																																					
Node System demonstration																																					

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY	Project (Number/Name) NET-02 / MARITIME SYSTEMS	

Schedule Details

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
Hydra				
Modular Enclosure Preliminary Design Review	3	2015	3	2015
Air Vehicle Initial Flight Test	4	2015	4	2015
Test Prototype Modular Enclosure	1	2016	1	2016
Critical Design Review of Undersea Payload and Air Vehicle Payload	2	2016	2	2016
Complete a Full Air Vehicle Flight Test	2	2017	2	2017
Demonstrate Full Undersea Payload Demonstration from the Modular Enclosure	4	2017	4	2017
Hybrid Multi Material Rotor Full Scale Demonstration (HyDem)				
Preliminary Design Review	2	2015	2	2015
Critical Design Review	3	2015	3	2015
Deliver Full Scale Component to Navy	3	2016	3	2016
Support Propulsor Integration on VIRGINIA Class Submarine	3	2016	2	2017
Support Propulsor Testing	3	2017	4	2017
Tactical Undersea Network Architecture				
System architecture design studies	2	2015	2	2015
Preliminary Design Review of system architecture	1	2016	1	2016
Component Testing	1	2016	1	2016
Software Design Review (SDR)	2	2017	2	2017
At-sea demonstration	4	2017	4	2017
Blue Wolf				
Initial Check-Out Testing	2	2015	2	2015
Design Safety Certification	4	2015	4	2017

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY		Project (Number/Name) NET-02 / MARITIME SYSTEMS	
	Start		End	
Events by Sub Project	Quarter	Year	Quarter	Year
Sub-System Hardware and Software Testing	2	2016	4	2017
Module Development and Fabrication	3	2016	4	2017
System At-Sea Testing	2	2017	2	2017
Complete System Integration	3	2017	3	2017
Positioning System for Deep Ocean Navigation (POSYDON)				
Program Initiation	1	2016	1	2016
Conduct at-sea data collections	1	2016	3	2016
Conduct real-time ranging demonstrations	1	2017	4	2017
Mobile Offboard Command, Control and Attack (MOCCA)				
Program Initiation	3	2016	3	2016
Evaluation testing of UUV mobile sonar	4	2017	4	2017
Virtual Acoustic Microphone Systems (VAMS)				
Program Initiation	3	2016	3	2016
System development and design review	4	2017	4	2017
Cross Domain Maritime Surveillance and Targeting (CDMaST)				
Program Initiation	3	2016	3	2016
Concept design for test bed environment	3	2017	3	2017
Distributed Agile Submarine Hunting (DASH)				
At sea sonar demonstrations	2	2015	2	2015
Node Design Validations	3	2015	1	2016
At sea mobile active sonar demonstrations	2	2016	4	2016
Node System demonstration	4	2016	4	2016

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603766E / NETWORK-CENTRIC WARFARE TECHNOLOGY				Project (Number/Name) NET-06 / NETWORK-CENTRIC WARFARE TECHNOLOGY			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
NET-06: NETWORK-CENTRIC WARFARE TECHNOLOGY	-	231.559	240.241	217.675	-	217.675	172.150	85.796	63.000	0.000	-	-
A. Mission Description and Budget Item Justification This project funds classified DARPA programs that are reported in accordance with Title 10, United States Code, Section 119(a)(1) in the Special Access Program Annual Report to Congress.												
B. Accomplishments/Planned Programs (\$ in Millions)									FY 2015	FY 2016	FY 2017	
Title: Classified DARPA Program Description: This project funds Classified DARPA Programs. Details of this submission are classified. FY 2015 Accomplishments: Details will be provided under separate cover. FY 2016 Plans: Details will be provided under separate cover. FY 2017 Plans: Details will be provided under separate cover.									231.559	240.241	217.675	
Accomplishments/Planned Programs Subtotals									231.559	240.241	217.675	
C. Other Program Funding Summary (\$ in Millions) N/A Remarks D. Acquisition Strategy N/A E. Performance Metrics Details will be provided under separate cover.												

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>					R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>							
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	283.905	240.127	241.288	-	241.288	207.325	197.278	236.505	270.554	-	-
SEN-01: <i>SURVEILLANCE AND COUNTERMEASURES TECHNOLOGY</i>	-	32.266	18.121	19.027	-	19.027	11.331	11.527	16.401	16.401	-	-
SEN-02: <i>SENSORS AND PROCESSING SYSTEMS</i>	-	115.315	116.396	145.732	-	145.732	149.194	167.876	215.104	254.153	-	-
SEN-03: <i>EXPLOITATION SYSTEMS</i>	-	48.924	13.411	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-
SEN-06: <i>SENSOR TECHNOLOGY</i>	-	87.400	92.199	76.529	-	76.529	46.800	17.875	5.000	0.000	-	-

A. Mission Description and Budget Item Justification

The Sensor Technology program element is budgeted in the Advanced Technology Development Budget Activity because it funds sensor efforts that will improve the accuracy and timeliness of our surveillance and targeting systems for improved battlefield awareness, strike capability and battle damage assessment.

The Surveillance and Countermeasures Technology project will improve the accuracy and timeliness of our surveillance and targeting systems for improved battlefield awareness, strike capability, and battle damage assessment. Timely surveillance of enemy territory under all weather conditions is critical to providing our forces with the tactical information needed to succeed in future wars. This operational surveillance capability must continue to perform during enemy efforts to deny and deceive the sensor systems, and operate, at times, in a clandestine manner. This project will exploit recent advances in multispectral target phenomenology, signal processing, low-power high-performance computing, and low-cost microelectronics to develop advanced surveillance and targeting systems. In addition, this project encompasses several advanced technologies related to the development of techniques to counter advanced battlefield threats.

The Sensors and Processing Systems project develops and demonstrates the advanced sensor processing technologies and systems necessary for intelligence surveillance and reconnaissance (ISR) missions. The project is primarily driven by four needs: 1) providing day-night ISR capabilities against the entire range of potential targets; 2) countering camouflage, concealment, and deception of mobile ground targets; 3) detecting and identifying objects of interest/targets across wide geographic areas in near-real-time; and 4) enabling reliable identification, precision fire control tracking, timely engagement, and accurate battle damage assessment of ground targets.

The Exploitation Systems project develops algorithms, software, and information processing systems to extract information from massive intelligence, surveillance, and reconnaissance (ISR) datasets. In particular, it develops new technologies for detection and discrimination of targets from clutter, classification and fingerprinting of high value targets, localization and tracking over wide areas, and threat network identification and analysis.

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 3: Advanced Technology Development (ATD)</i>	R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	302.821	257.127	275.921	-	275.921
Current President's Budget	283.905	240.127	241.288	-	241.288
Total Adjustments	-18.916	-17.000	-34.633	-	-34.633
• Congressional General Reductions	0.000	-6.000			
• Congressional Directed Reductions	0.000	-11.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	-9.693	0.000			
• SBIR/STTR Transfer	-9.223	0.000			
• TotalOtherAdjustments	-	-	-34.633	-	-34.633

Change Summary Explanation

FY 2015: Decrease reflects reprogrammings and the SBIR/STTR transfer.

FY 2016: Decrease reflects congressional reduction.

FY 2017: Decrease reflects completion of Insight and drawdown of classified programs.

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>				Project (Number/Name) SEN-01 / <i>SURVEILLANCE AND COUNTERMEASURES TECHNOLOGY</i>			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
SEN-01: <i>SURVEILLANCE AND COUNTERMEASURES TECHNOLOGY</i>	-	32.266	18.121	19.027	-	19.027	11.331	11.527	16.401	16.401	-	-
A. Mission Description and Budget Item Justification												
This project funds sensor efforts that will improve the accuracy and timeliness of our surveillance and targeting systems for improved battlefield awareness, strike capability, and battle damage assessment. Timely surveillance of enemy territory under all weather conditions is critical to providing our forces with the tactical information needed to succeed in future wars. This operational surveillance capability must continue to perform during enemy efforts to deny and deceive the sensor systems, and operate, at times, in a clandestine manner. This project will exploit recent advances in multispectral target phenomenology, signal processing, low-power high-performance computing, and low-cost microelectronics to develop advanced surveillance and targeting systems. In addition, this project encompasses several advanced technologies related to the development of techniques to counter advanced battlefield threats.												
B. Accomplishments/Planned Programs (\$ in Millions)									FY 2015	FY 2016	FY 2017	
Title: Multi-Optical Sensing (MOS)*									18.060	18.121	19.027	
Description: *Formerly Multi-Function Optical Sensing (MOS)												
The proliferation of radio frequency (RF)-based countermeasures, such as digital radio frequency memory (DRFM), has presented challenges to the effectiveness of data sensors. The Multi-Optical Sensing (MOS) program will enable an alternative approach to detecting, tracking, and performing non-cooperative target identification, as well as providing fire control for fighter class and long-range strike aircraft. This program leverages emerging high-sensitivity focal plane array (FPA) and compact, multiband laser systems technology in the near/mid/long-wave infrared bands to enable the development of a multi-optical sensing system. Technical challenges include the demonstration of inexpensive, multiband, large-format, photon-counting, high-bandwidth receivers and their integration into a multi-optical sensor suite compatible with airborne assets. The MOS program seeks to advance the state of the art of components and technology to support an all-optical airborne system that can detect, geolocate, and identify targets at standoff ranges. Technologies from this program will transition to the Services.												
FY 2015 Accomplishments:												
- Completed initial capability demonstrations, which collected target imagery used to baseline simulations.												
- Initiated the development of the first-generation prototype system.												
- Incorporated advanced data processing and target tracking algorithms into the sensor processing chain.												
- Demonstrated capability of active focal plane arrays and variable waveform lasers to meet the desired detection performance.												
- Initiated packaging activity for the incorporation of the developed active focal plane arrays and variable waveform lasers into the second-generation architecture.												

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>	Project (Number/Name) SEN-01 / <i>SURVEILLANCE AND COUNTERMEASURES TECHNOLOGY</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Developed a hardware traceability strategy for the second-generation prototype sensor, which will be part of a roadmap for the development of a fully operational system. FY 2016 Plans: - Complete the development of the first-generation prototype system. - Perform air-to-air demonstrations with the first-generation prototype system. - Initiate the development of a second-generation prototype system, which will demonstrate the full capability out to operational ranges. FY 2017 Plans: - Complete the development of the second-generation prototype system and integrate onto an airborne platform. - Perform air-to-air demonstrations with the second-generation prototype system. - Demonstrate the full capability of the second-generation prototype system out to operational ranges.			
Title: Adaptable Navigation Systems (ANS) Description: The Adaptable Navigation Systems (ANS) program provided the U.S. warfighter with the ability to effectively navigate challenging environments including when Global Positioning System (GPS) is unavailable due to hostile action (jamming) or blockage by structures, foliage, or other environmental obstacles. The ANS approach relied on three major technology innovations. The first was the development of a new type of inertial measurement unit (IMU) that required fewer GPS position fixes. Using cold atom technology, this IMU exceeds the performance of strategic-grade IMUs, with comparable size, weight, and power (SWaP). The second innovation used Signals of Opportunity (SoOp) from a variety of ground-, air-, and space-based sources, as well as natural SoOps to reduce dependency on GPS position fixes. The third technology innovation allowed SoOp-based position information to be combined with inertial and other sensors to enable flexible navigation systems that can be reconfigured in the field to support any platform or environment. This capability enhanced new advanced component technology for positioning, navigation, and timing (PNT) emerging from other programs in the form of Micro Electro-Mechanical System devices, clocks, and new aiding sensors. Recent advances in mathematics, data abstraction, and network architectures built upon these capabilities by enabling "plug-and-play" integration of both existing and future navigation components and processing to allow real-time reconfiguration of navigation systems. Major improvements in navigation accuracy and system cost were also realized. Potential transition partners include all Services, with emphasis on platforms and users that must operate in multiple environments, such as Naval forces. FY 2015 Accomplishments: - Designed, built, and evaluated components of a cold atom interferometer for inertial sensing. - Demonstrated the navigation performance, independent of GPS, of the integrated ANS system, comprised of various sensors, including IMUs and SoOp receivers, and a sensor fusion processor, on multiple sea-, air-, and land-based platforms.		11.482	-
			-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016			
Appropriation/Budget Activity 0400 / 3		R-1 Program Element (Number/Name) PE 0603767E / SENSOR TECHNOLOGY	Project (Number/Name) SEN-01 / SURVEILLANCE AND COUNTERMEASURES TECHNOLOGY		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017	
- Integrated additional ship-based non-navigation sensors into an ANS system and demonstrated GPS-independent navigation at sea to effect transition to the Navy.					
Title: Adaptable, Low Cost Sensors (ADAPT)		2.724	-	-	
Description: The objective of the Adaptable, Low Cost Sensors (ADAPT) program was to leverage commercial technology and manufacturing techniques to improve the development time and significantly reduce the cost of sensors and sensor systems. Currently, military sensors are designed and developed with unique, mission-specific hardware and software capability requirements in a single, fully integrated device. This approach significantly increases both the cost and difficulty of meeting continuously changing requirements and upgrades. Commercial processes, such as those used in the smart phone industry, create reference designs for common system functions and features to accelerate system development time. This makes changing requirements and completing upgrades far simpler. Adopting these commercial processes enables a mission-independent, designed-to-cost "commercial smart core" that can be combined with an appliqué of mission-specific hardware to provide low-cost, independently upgradable, and previously infeasible sensor system distribution capabilities. The ADAPT Smart Munitions effort has applied ADAPT's sensing, processing, communications, and location capabilities to provide positive identification and man-in-the-loop control of distributed, unattended ground sensor systems. It also developed a reference design to demonstrate capability and develop tactics for unattended sensors. This program will transition to the Army and Navy.					
FY 2015 Accomplishments:					
- Field tested and demonstrated mobile coordinated device operation using ADAPT reference designs (Smart Munitions and UAVs).					
- Investigated alternative low-cost sensor designs for other small form factor unmanned military platforms.					
- Completed development and testing of the ADAPT reference designs.					
- Transitioned reference designs to the Army and Navy.					
Accomplishments/Planned Programs Subtotals		32.266	18.121	19.027	
C. Other Program Funding Summary (\$ in Millions)					
N/A					
Remarks					
D. Acquisition Strategy					
N/A					
E. Performance Metrics					
Specific programmatic performance metrics are listed above in the program accomplishments and plans section.					

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603767E / SENSOR TECHNOLOGY				Project (Number/Name) SEN-01 / SURVEILLANCE AND COUNTERMEASURES TECHNOLOGY					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
ADAPT	C/Various	Various : Various	-	1.755		0.000		0.000		-		0.000	0	1.755	0
Adaptable Navigation Systems	C/Various	Various : Various	-	7.692		0.000		0.000		-		0.000	0	7.692	0
Multi Optical Sensing	C/CPFF	Various : Various	-	2.547		5.475		5.655		-		5.655	Continuing	Continuing	Continuing
Multi Optical Sensing	C/CPFF	BAE SYSTEMS INTEGRATION I : NH	-	7.014	Mar 2015	0.000		0.000		-		0.000	0	7.014	0
Multi Optical Sensing	C/CPFF	RAYTHEON COMPANY : CA	-	7.729	Sep 2015	10.624		11.660		-		11.660	Continuing	Continuing	Continuing
Subtotal			-	26.737		16.099		17.315		-		17.315	-	-	-
Support (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Government Support	C/Various	Various : Various	-	1.291		0.725		0.761		-		0.761	Continuing	Continuing	Continuing
Subtotal			-	1.291		0.725		0.761		-		0.761	-	-	-
Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
ADAPT	MIPR	Various : Various	-	0.186		0.000		0.000		-		0.000	0	0.186	0
Adaptable Navigation Systems	MIPR	Various : Various	-	1.945		0.000		0.000		-		0.000	0	1.945	0
Multi Optical Sensing	SS/CPFF	MIT LINCOLN LABORATORY : MA	-	0.494	Apr 2015	0.391		0.000		-		0.000	0	0.885	0
Subtotal			-	2.625		0.391		0.000		-		0.000	0.000	3.016	0.000

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016		
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>				Project (Number/Name) SEN-01 / <i>SURVEILLANCE AND COUNTERMEASURES TECHNOLOGY</i>				

Management Services (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Management Support	C/Various	Various : Various	-	1.613		0.906		0.951		-		0.951	Continuing	Continuing	Continuing
Subtotal			-	1.613		0.906		0.951		-		0.951	-	-	-

	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	Cost To Complete	Total Cost	Target Value of Contract
Project Cost Totals	-	32.266	18.121	19.027	-	19.027	-	-	-

Remarks

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>	Project (Number/Name) SEN-01 / <i>SURVEILLANCE AND COUNTERMEASURES TECHNOLOGY</i>

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
<i>Multi-Optical Sensing (MOS)</i>																												
Prototype System Development																												
Prototype air-to-air demonstrations																												
Prototype system integration																												
Full Prototype demonstration																												
<i>Adaptable Navigation Systems (ANS)</i>																												
GPS-independent navigation demonstrations on air, land, and sea platforms																												
Cold atom IMU testing																												
<i>Adaptable, Low Cost Sensors (ADAPT)</i>																												
Field testing and demonstrating																												

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>	Project (Number/Name) SEN-01 / <i>SURVEILLANCE AND COUNTERMEASURES TECHNOLOGY</i>

Schedule Details

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
<i>Multi-Optical Sensing (MOS)</i>				
Prototype System Development	1	2015	3	2016
Prototype air-to-air demonstrations	3	2016	3	2016
Prototype system integration	4	2016	3	2017
Full Prototype demonstration	4	2017	4	2017
<i>Adaptable Navigation Systems (ANS)</i>				
GPS-independent navigation demonstrations on air, land, and sea platforms	1	2015	1	2015
Cold atom IMU testing	3	2015	3	2015
<i>Adaptable, Low Cost Sensors (ADAPT)</i>				
Field testing and demonstrating	4	2015	4	2015

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>				Project (Number/Name) SEN-02 / <i>SENSORS AND PROCESSING SYSTEMS</i>			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
SEN-02: <i>SENSORS AND PROCESSING SYSTEMS</i>	-	115.315	116.396	145.732	-	145.732	149.194	167.876	215.104	254.153	-	-

A. Mission Description and Budget Item Justification

The Sensors and Processing Systems project develops and demonstrates the advanced sensor and processing technologies and systems necessary for intelligence, surveillance, and reconnaissance (ISR) missions. Future battlefields will continue to be populated with targets that use mobility and concealment as key survival tactics, and high-value targets will range from specific individual insurgents and vehicles to groups of individuals and large platforms such as mobile missile launchers and artillery. The Sensors and Processing Systems Project is primarily driven by four needs: (a) providing day-night ISR capabilities against the entire range of potential targets; (b) countering camouflage, concealment, and deception of mobile ground targets; (c) detecting and identifying objects of interest/targets across wide geographic areas in near-real-time; and (d) enabling reliable identification, precision fire control tracking, timely engagement, and accurate battle damage assessment of ground targets. The Sensors and Processing Systems Project develops and demonstrates technologies and system concepts that combine novel approaches to sensing with emerging sensor technologies and advanced sensor and image processing algorithms, software, and hardware to enable comprehensive knowledge of the battlespace and detection, identification, tracking, engagement, and battle damage assessment for high-value targets in all weather conditions and combat environments.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Adaptive Radar Countermeasures (ARC)	26.475	20.512	19.487
Description: The goal of the Adaptive Radar Countermeasures (ARC) program is to provide effective electronic countermeasure (ECM) techniques against new or unknown threat radars. Current airborne electronic warfare (EW) systems rely on the ability to uniquely identify a threat radar system to apply an appropriate preprogrammed countermeasure technique which can take many months to develop. Countering radar systems is increasingly challenging as digitally programmed radars exhibit novel behaviors and agile waveform characteristics. ARC will develop new processing techniques and algorithms that adapt in real-time to generate suitable countermeasures. Using techniques such as state modeling, machine learning, and system probing, ARC will learn the behavior of the threat system, then choose and implement an appropriate countermeasure strategy. The program is planned for transition to Air Force, Navy, and Marine Corps airborne EW systems. FY 2015 Accomplishments: - Refined and integrated component algorithms for end-to-end system testing in simulation. - Developed adaptive radar threat models for use in testing which emulate future adversary radar capabilities that are expected to challenge current baseline EW systems. - Began porting software algorithms onto transition partner provided baseline EW systems to demonstrate enhanced performance against unknown or ambiguous threat radars. FY 2016 Plans:			

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / SENSOR TECHNOLOGY	Project (Number/Name) SEN-02 / SENSORS AND PROCESSING SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Complete real-time software and firmware implementation of all major algorithm modules on transition partner provided baseline EW systems. - Refine adaptive radar threat models for use in testing which emulate future adversary radar capabilities that are expected to challenge current baseline EW systems. - Demonstrate real-time prototype systems by effectively operating against unanticipated or ambiguous radar signals in a hardware-in-the-loop laboratory environment. FY 2017 Plans: - Develop detailed flight test plans in concert with relevant programs of record and Service partners. - Identify test ranges and relevant assets which can emulate modern unanticipated and ambiguous radar signals in an open-air testing environment. - Update software algorithms testing robustness to realistic RF test conditions using emulation in real-time laboratory testing and stationary open-air tests.				
Title: Spatial, Temporal and Orientation Information for Contested Environments (STOIC) Description: Building on technologies developed in the Adaptable Navigation Systems (ANS) program, budgeted in PE 0603767E, Project SEN-01, the Spatial, Temporal and Orientation Information for Contested Environments (STOIC) program will enable precision cooperative effects by developing global time transfer and synchronization systems independent of GPS. As a corollary to time synchronization, this program will also enable GPS-independent positioning to maintain precise time synchronization between collaborating mobile users. Key attributes of this program are global availability; minimal and low cost infrastructure; anti-jamming capability; and performance equal to or better than GPS through recent advances in optical clocks and time transfer. Demonstrations on relevant platforms in relevant environments will be used to validate the technology. This program will transition to the Services, emphasizing platforms that operate in GPS-denied environments. FY 2015 Accomplishments: - Began developing a compact optical clock that maintains GPS-level time for over a year. - Began developing a wireless precision time transfer system that provides better than GPS-level performance using tactical data links. - Began developing jam-proof PNT systems that provide GPS-level performance in contested environments. FY 2016 Plans: - Complete prototype components of optical clocks. - Complete detailed design and begin development of compact optical clocks. - Develop prototype components and systems for enabling precision time transfer independent of GPS. - Complete detailed design and begin development of GPS-independent precision time transfer systems.		18.425	23.500	21.365

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / SENSOR TECHNOLOGY	Project (Number/Name) SEN-02 / SENSORS AND PROCESSING SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Develop prototype jam-proof PNT system components (signal transmit and receive) for achieving GPS-level positioning performance in contested environments. - Complete detailed design and begin development of jam-proof PNT system based on very low frequency (VLF) transmitters and waveforms. FY 2017 Plans: - Commence integration and testing of compact optical clocks. - Complete development of prototype GPS-independent precision time transfer system and begin system evaluations. - Complete development of jam-proof PNT system and conduct tests to validate system performance.				
Title: Automatic Target Recognition (ATR) Technology Description: Automatic Target Recognition (ATR) systems provide the capability to detect, identify, and track high value targets from collected sensor data. Current ATRs are typically designed for specific sensors and static due to pre-programmed target lists and operating mode, limiting mission execution capabilities. Extending ATR Technology to accommodate sensor upgrades or include new emerging targets can be costly and time consuming. The objective of the ATR Technology program is to develop technologies that reduce operation limitations while also providing significant performance improvements, dramatically reduced development times, and reduced life cycle maintenance costs. Recent breakthroughs in deep learning, sparse representations, manifold learning, and embedded systems offer promise for dramatic improvements in ATR Technology. The program will focus on three core areas: (1) development of on-line adaptive algorithms that enable performance-driven sensing and ATR technology; (2) recognition technology that enables rapid incorporation of new targets; and (3) technologies that dramatically reduce required data rates, processing times, and the overall hardware and software footprint of ATR systems. ATR technology developed under the program is planned for transition to the Services. FY 2015 Accomplishments: - Developed a modeling and simulation framework for testing and evaluating performance-driven ATR systems. - Established baseline performance for existing radar ATR algorithms against challenge problem data sets. - Designed and executed a data collection experiment to provide additional data for algorithm development and testing. - Initiated development of advanced algorithms that support signature generalization and reduced signature database complexity. FY 2016 Plans: - Initiate design of an embedded real-time, low-cost radar ATR processor that incorporates advanced ATR algorithms and uses commercial mobile embedded computing platforms. - Design and execute additional data collection experiments for continued algorithm development and testing. - Continue to improve ATR algorithm performance, including decoy rejection and false target rejection. FY 2017 Plans:		11.500	18.000	24.759

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / SENSOR TECHNOLOGY	Project (Number/Name) SEN-02 / SENSORS AND PROCESSING SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Develop adaptable ATR algorithms to rapidly learn new targets with minimal measured data and evaluate algorithm learning rate. - Continue to improve ATR algorithm performance, focusing on false-alarm performance. - Complete design and begin development of a flightworthy, low-power ATR processing hardware that executes the ATR algorithm in real-time.				
Title: Advanced Scanning Technology for Imaging Radars (ASTIR) Description: The Advanced Scanning Technology for Imaging Radars (ASTIR) program will provide immediate benefit to applications that are constrained by power, weight, and the complexity limits of production. The goal of this program, building on technologies developed under the Multifunction RF (MFRF) program which is budgeted in this PE/Project, is to demonstrate a new imaging radar architecture using an electronically scanned sub-reflector to produce a more readily available, cost-effective sensor solution that does not require platform or target motion. Key system attributes will: (1) provide high-resolution 3D imaging for enhanced identification and targeting, independent of platform or target motion; (2) produce video frame rates to provide well-focused images even when there is platform or target motion; (3) beam steer with a single transmit/receive chain to reduce system complexity resulting in lower cost, power, and weight; and (4) integrate millimeter-wave (mmW)/terahertz (THz) electronic component advancements from other DARPA programs for transmit and receive functions. The completion of this program will result in a more readily available, cost-effective imaging radar technology that will work in concert with a wide area surveillance system to provide target identification at video frame rates in all conditions where existing sensors will not work. Candidate military applications include efficient terminal seekers, imaging systems for defense of shipping in ports and littoral environments, base perimeter monitoring, and screening of personnel passing through access control points. This technology is intended to transition to Special Operations Command and the Navy. FY 2016 Plans: - Develop sensor design concepts and define processing requirements. - Build prototype electronic sub-reflector beam-steering systems and conduct tests to characterize performance and validate approach. - Conduct mission studies and determine the system performance metrics required to support specific candidate military applications. FY 2017 Plans: - Complete assessments of candidate military applications and show benefit from technologies developed under this effort. - Complete electronically scanned sub-reflector sensor requirements. - Design imaging radar system utilizing technologies developed under this effort to address additional military applications.		-	9.988	13.985
Title: Small Satellite Sensors		-	8.000	24.478

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / SENSOR TECHNOLOGY	Project (Number/Name) SEN-02 / SENSORS AND PROCESSING SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Description: Building upon low-cost and small form factor sensor research conducted under DARPA's Adaptable, Low Cost Sensors (ADAPT) and Multi-Optical Sensing (MOS) programs (budgeted in PE 0603767E, Project SEN-01), the Small Satellite Sensors program will develop and space-qualify electro-optical and infrared (EO/IR) sensor and inter-satellite communications technologies, and establish feasibility that new DoD tactical capabilities can be implemented on small (< 100 lb) satellites. Experimental payloads will be flown on small satellites, and data will be collected to validate new operational concepts. Small satellites provide a low-cost and quick-turnaround capability for testing new technologies and experimental payloads. Operationally, small and low-cost satellites enable the deployment of larger constellations which can provide greater coverage, persistence, and survivability compared to a small number of more expensive satellites, as well as the possibility for launch-on-demand. This program seeks to leverage rapid progress being made by the commercial sector on small satellite bus technology, as well as investments being made by DoD and industry on low-cost launch and launch-on-demand capabilities for small satellites. The program will focus on developing, demonstrating, and validating key payload technologies needed by DoD that are not currently being developed for commercial space applications. Technologies developed under this program will transition to the Air Force. FY 2016 Plans: - Develop conceptual designs for EO/IR sensor and inter-satellite communications link subsystems. - Develop software performance models for candidate sensor systems, and perform laboratory or airborne testing to improve model fidelity and assist in design of flight hardware. - Begin design of experimental sensor payloads compatible with a small satellite bus, and perform preliminary design review. - Begin development of lightweight and low-power inter-satellite communications links suitable for providing high-bandwidth crosslinks for 100 lb class satellites. - Investigate alternative low-cost payloads suitable for integration on a small satellite. FY 2017 Plans: - Complete detailed design of small satellite EO/IR sensor, and complete a preliminary design review. - Complete construction of the small EO/IR payload and satellite bus. - Build inter-satellite communications link hardware for integration into satellites. - Develop and test mission data processing software. - Develop detailed plan for on-orbit operations.				
Title: Seeker Cost Transformation (SECTR)* Description: *Formerly Low Cost Seeker		-	8.000	20.658

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / SENSOR TECHNOLOGY	Project (Number/Name) SEN-02 / SENSORS AND PROCESSING SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
The Seeker Cost Transformation (SECTR) program will develop novel weapon terminal sensing and guidance technologies and systems, for air-launched and air-delivered weapons, that can: (1) find and acquire fixed and moving targets with only minimal external support; (2) achieve high navigation accuracy in a GPS-denied environment; and (3) have very small size and weight, and potentially low cost. The development objectives are technologies and systems with small size, weight and power (SWaP), low recurring cost, applicability to a wide range of weapons and missions such as small unit operations, suppression of enemy air defenses, precision strike, and time-sensitive targets. The technical approach for the sensing/processing hardware is to use both passive electro-optical infrared (EO/IR) sensors, which have evolved into very small and inexpensive devices in the commercial market, and a reconfigurable processing architecture, such as the architecture developed in DARPA's ADAPT program (budgeted in PE 0603767E, Project SEN-01). The program will also develop a Government-owned open architecture for the seeker with standardized interfaces between components (both hardware and software). The technical approach to target recognition will start from "deep learning" and 2D/3D machine vision algorithms pioneered for facial recognition and the identification of critical image features. Technologies developed under this program will transition to the Services. FY 2016 Plans: - Initiate development of core seeker system engineering design. - Initiate development of open seeker standard interfaces. - Develop small size, weight, and power (SWaP) and cost sensor and processing unit. - Design novel target recognition algorithms. - Design GPS-free image navigation and processing sensor and algorithm. - Perform initial hardware-in-the-loop (HWIL) test for GPS-free navigation unit. - Perform initial HWIL test for target recognition algorithms. FY 2017 Plans: - Conduct laboratory demonstrations of sensor/processing unit. - Conduct captive flight test of small SWaP sensor/processing unit. - Conduct laboratory demonstrations of GPS-free navigation algorithms. - Conduct laboratory demonstration of target recognition algorithms. - Integrate GPS-free navigation algorithm and target recognition algorithms into the small SWaP sensors/processing unit. - Complete and distribute seeker open standard interfaces.				
Title: Unbanded SPectrum operatIoNs (U-SPIN) Description: The goal of the Unbanded SPectrum operatIoNs (U-SPIN) program is to develop technologies which enable interoperability of multiple spectrum objectives simultaneously. Currently, U.S. forces divide the RF spectrum into "bands" to deconflict specific functions which are considered incompatible with one another (for example, communications, electronic warfare, signals intelligence, and RADAR). This approach relies on a static RF environment and accurate intelligence about		-	-	7.000

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>	Project (Number/Name) SEN-02 / <i>SENSORS AND PROCESSING SYSTEMS</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
the opposing force's spectrum capabilities and allocations. It also enables the enemy to accurately predict where and what our spectrum functions will be. U-SPIN will demonstrate the ability to dynamically co-design the previously incompatible functions on-the-fly using learned knowledge about the RF environment.			
FY 2017 Plans: - Initiate algorithmic study of techniques that can achieve multiple spectrum objectives simultaneously. - Select best of breed application of technology (achieving at least two functions simultaneously) and demonstrate proof of concept in a laboratory setting.			
Title: Dynamically Composed RF Systems Description: Dominance of the RF spectrum is critical to successful U.S. military operations. Radar systems, electronic warfare (EW) systems, and communication systems require custom software and hardware that is costly and time consuming to build and integrate onto platforms. Expanding on ideas developed under the Multifunction RF program, also in this PE, the Dynamically Composed RF Systems program addresses these challenges by developing adaptive, converged RF array systems. This enables enhanced operational capability by dynamically adapting the system for tasks to support radar, communications, and EW in a converged manner. This program will design and develop: (1) a modular architecture for collaborative, agile RF systems; (2) advanced techniques for RF apertures and their associated airframe integration; (3) wide-band agile electronics to support converged missions over those apertures; and (4) software tools for the control, coordination, and scheduling of RF functions and payloads at the element level to maximize overall task performance. This capability can be adapted to address diverse missions. Technology developed under this program will transition to the Services. FY 2017 Plans: - Assemble requirements to provide an abstraction of underlying software and hardware architectures. - Commence design of modular architecture for agile, collaborative converged RF systems. - Commence design of RF apertures and associated airframe integration, and agile low-power wide-band RF electronics suitable for an RF payload on low-cost platforms/UAVs. - Commence development of software for controlling and scheduling RF hardware (including processor) to carry out the desired RF functions.		-	-
Title: Multifunction RF (MFRF) Description: The Multifunction RF (MFRF) program goal is to enable U.S. rotary wing aircraft forces to fight effectively in all forms of severely Degraded Visual Environments (DVE) when our adversaries cannot. The program goes beyond landing aids in DVE to address all elements of combat to include landing, takeoff, hover/taxi, enroute navigation, lethality, and survivability. Building on previous RF sensors advancements, the program will seek to eliminate many redundant RF elements of current		12.075	6.385
			-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>	Project (Number/Name) SEN-02 / <i>SENSORS AND PROCESSING SYSTEMS</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
independently developed situational and combat support systems to provide multifunction capability with flexibility of adding new mission functions. This will reduce the overall size, weight, power, and cost (SWaP-C) of subsystems and protrusive exterior antennas on military aircraft, enabling greater mission capability with reduced vehicle system integration burden. The program approach includes: (1) development of synthetic vision for pilots that fuses sensor data with high-resolution terrain databases; (2) development of Advanced Rotary Multifunction Sensor (ARMS), utilizing silicon-based tile arrays, for agile electronically scanning technology at low SWaP-C; and (3) implementation of software development kit to re-define modes as required by mission or platform needs, and ease of adding new modes via software without hardware modifications. The program is planned for transition to the Army and Marines. FY 2015 Accomplishments: - Demonstrated utility of software development kit through third-party programming. - Selected test platform and began modifications on Army helicopter for flight testing ARMS sensor. - Investigated alternative imaging radar architectures to further reduce size, weight, power, and cost. - Successfully built two unique tile prototype designs and selected final design for demonstration array. FY 2016 Plans: - Conduct laboratory and field demonstrations with integrated ARMS, synthetic vision backbone, other potential collision avoidance sensors and multifunction software development kit. - Demonstrate DVE landing, takeoff, Ground Moving Target Indicator (GMTI), and Synthetic Aperture Radar (SAR) modes of operation. - Conduct flight tests of ARMS integrated with synthetic vision system on an Army helicopter in cooperation with CERDEC and AMRDEC. - Transition DVE system to the Army. - Further explore RF technologies to determine feasibility of capability convergence.			
Title: Video-rate Synthetic Aperture Radar (ViSAR) Description: Recent conflicts have demonstrated the need for close air support by precision attack platforms such as the AC-130J aircraft in support of ground forces. Under clear conditions, targets are easily identified and engaged quite effectively, but in degraded environments, the atmosphere can inhibit traditional optical sensors. The AC-130J must fly above cloud decks in order to avoid anti-aircraft fire, negating optical targeting sensors. Similarly, rotary/wing blades in urban operations generate copious amounts of dust that prevent circling assets from supplying cover fire for ground forces. The Video-rate Synthetic Aperture Radar (ViSAR) program seeks to develop a real-time spotlight synthetic aperture radar (SAR) imaging sensor that will provide imagery of a region to allow high-resolution fire direction in conditions where optical sensors do not function. Technology from this program is planned to transition to Air Force Special Operations Command (AFSOC).		18.847	12.250
			-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / SENSOR TECHNOLOGY	Project (Number/Name) SEN-02 / SENSORS AND PROCESSING SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
FY 2015 Accomplishments: - Completed development and testing of prototype high power amplifier. - Demonstrated the integration of low power transmitter and receiver components into sensor and conducted over-the-air testing to validate system performance. - Integrated phenomenology data into scene simulator and generated data for demonstration of algorithm performance.				
FY 2016 Plans: - Complete development and unit-level testing of flightworthy high power amplifier. - Integrate hardware into a sensor control system (gimbal) and demonstrate performance in a laboratory scenario, and in over-the-air testing against calibration targets. - Integrate hardware and gimbal on a surrogate aircraft. - Begin flight tests to demonstrate ViSAR performance in comparison to Electro-Optic sensors. - Conduct flight demonstrations in cooperation with AFRL and AFSOC.				
Title: Military Imaging and Surveillance Technology (MIST) Description: The Military Imaging and Surveillance Technology (MIST) program is developing a fundamentally new optical Intelligence, Surveillance, and Reconnaissance (ISR) capability that can provide high-resolution 3-D images to locate and identify a target at much longer ranges than is possible with existing optical systems. Short, moderate, and long-range prototype optical surveillance and observation systems are being developed that: (1) demonstrate probabilities of recognition and identification at distances sufficient to allow stand-off engagement; (2) overcome atmospheric turbulence, which now limits the ability of high-resolution optics; and (3) increase target identification confidence to reduce fratricide and/or collateral damage. The program will develop and integrate the necessary component technologies including high-energy pulsed lasers, receiver telescopes that have a field of view and depth of field that obviates the need for steering or focusing the optical system, computational imaging algorithms to improve system resolution, and data exploitation and analysis tools. Advances in laser systems, digital imagers, and novel image processing algorithms will be leveraged to reduce the overall size, weight, and power (SWaP) of imaging systems to allow for soldier portable and Unmanned Aerial Vehicle (UAV) platform integration. The MIST program will transition the optical ISR technology to the Services and SOCOM.		22.493	9.761	-
FY 2015 Accomplishments: - Continued the development of a short-range 3-D imaging system. - Completed ground demonstrations of the moderate and long-range 3-D imaging systems, including testing and demonstration of critical subsystem components. - Completed a packaging study and testing of the MIST high-energy pulsed laser.				

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / SENSOR TECHNOLOGY	Project (Number/Name) SEN-02 / SENSORS AND PROCESSING SYSTEMS		
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
- Initiated the development of a mountain-to-ground demonstration capability for the moderate-range 3-D imaging system. FY 2016 Plans: - Complete the development of the short-range 3-D imaging system. - Demonstrate the capabilities of the completed short-range 3-D imaging system - Complete the development of the mountain-to-ground demonstration capability for the moderate-range 3-D imaging system. - Conduct mountain-to-ground demonstrations of the moderate-range 3-D imaging system. - Transition the short-range and moderate-range 3-D imaging system to the Services and SOCOM.				
Title: Behavioral Learning for Adaptive Electronic Warfare (BLADE) Description: The Behavioral Learning for Adaptive Electronic Warfare (BLADE) program developed the capability to jam adaptive and rapidly evolving wireless communication threats in tactical environments and at tactically-relevant timescales. This has changed the paradigm for responding to evolving threats from lab-based manual development to an adaptive in-the-field systems approach. When an unknown or adaptive communication threat appears in theater, BLADE dynamically characterized the communication network, synthesized an effective countering technique, and evaluated jamming effectiveness by iteratively probing, learning, and adapting to the threat. An optimization process tailored real-time responses to specific threats, producing a countermeasure waveform that maximizes jam effectiveness while minimizing the required jamming resources. BLADE enabled the rapid defeat of new communication threats and provided the warfighter with real-time feedback on jam effectiveness. The program transitioned to the U.S. Army Communications-Electronic RDT&E Center, Intelligence and Information Warfighter Directorate for further maturation and hardening. FY 2015 Accomplishments: - Tested and evaluated ground-based and airborne prototype systems in an operationally relevant over-the-air environment featuring agile and commercial communications threat networks. - Quantified the minimum hardware requirements, including processing and memory, necessary to execute the BLADE algorithms on transition platforms. - Transitioned BLADE components to U.S. Army Communications-Electronic RDT&E Center Intelligence and Information Warfare Directorate. - Executed an Airborne demonstration against tactically relevant threat networks at Electronics Proving Ground, Ft. Huachuca, AZ, to transition partners.		5.500	-	-
Accomplishments/Planned Programs Subtotals		115.315	116.396	145.732
C. Other Program Funding Summary (\$ in Millions)				
N/A				

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>	Project (Number/Name) SEN-02 / <i>SENSORS AND PROCESSING SYSTEMS</i>
C. Other Program Funding Summary (\$ in Millions) <u>Remarks</u> D. Acquisition Strategy N/A E. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.		

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>				Project (Number/Name) SEN-02 / <i>SENSORS AND PROCESSING SYSTEMS</i>					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Adaptive Radar Countermeasures (ARC)	C/CPFF	Leidos : VA	-	8.450	Dec 2015	8.456		9.265		-		9.265	Continuing	Continuing	Continuing
Adaptive Radar Countermeasures (ARC)	C/CPFF	BAE : NH	-	9.350	Nov 2015	0.224		0.520		-		0.520	Continuing	Continuing	Continuing
Adaptive Radar Countermeasures (ARC)	C/CPFF	Various : Various	-	7.403		9.692		7.742		-		7.742	Continuing	Continuing	Continuing
Spatial, Temporal and Orientation Information for Contested Environments	C/Various	Various : Various	-	12.128		20.226		16.829		-		16.829	Continuing	Continuing	Continuing
Spatial, Temporal and Orientation Information for Contested Environments	C/CPFF	ROCKWELL COLLINS,INC. : IA	-	5.391	Apr 2015	0.000		0.000		-		0.000	0	5.391	0
Automatic Target Recognition (ATR) Technology	C/Various	Various : Various	-	8.934		15.853		22.730		-		22.730	Continuing	Continuing	Continuing
Advanced Scanning Technology for Imaging Radars (ASTIR)	C/Various	Various : Various	-	0.000		9.694		11.903		-		11.903	Continuing	Continuing	Continuing
Small Satellite Sensors	C/Various	Various : Various	-	0.000		7.823		22.763		-		22.763	Continuing	Continuing	Continuing
Seeker Cost Transformation (SECTR)*	C/CPFF	Various : Various	-	0.000		6.888		17.935		-		17.935	Continuing	Continuing	Continuing
Unbanded SPectrum operatIoNs (U-SPIN)	C/TBD	Various : Various	-	0.000		0.000		6.568		-		6.568	Continuing	Continuing	Continuing
Dynamically Composed RF Systems	C/TBD	Various : Various	-	0.000		0.000		13.212		-		13.212	Continuing	Continuing	Continuing
Multifunction RF (MFRF)	C/Various	Various : Various	-	9.702		4.801		0.000		-		0.000	0	14.503	0
Video-rate Synthetic Aperture Radar (ViSAR)	C/Various	Various : Various	-	16.586		10.965		0.000		-		0.000	0	27.551	0
Military Imaging and Surveillance Technology (MIST)	C/CPFF	TREX ENTERPRISES CORPORATION : CA	-	19.315	Mar 2015	7.835		0.000		-		0.000	0	27.150	0

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603767E / SENSOR TECHNOLOGY				Project (Number/Name) SEN-02 / SENSORS AND PROCESSING SYSTEMS					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Behavioral Learning for Adaptive Electronic Warfare (BLADE)	C/CPFF	LOCKHEED MARTIN CORPORATION : CA	-	5.148		0.000		0.000		-		0.000	0	5.148	0
Subtotal			-	102.407		102.457		129.467		-		129.467	-	-	-
Support (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Government Support	MIPR	Various : Various	-	4.613		4.656		5.829		-		5.829	Continuing	Continuing	Continuing
Subtotal			-	4.613		4.656		5.829		-		5.829	-	-	-
Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Spatial, Temporal and Orientation Information for Contested Environments	C/Various	Various : Various	-	0.457		0.440		1.321		-		1.321	Continuing	Continuing	Continuing
Automatic Target Recognition (ATR) Technology	C/Various	Various : Various	-	1.635		0.000		0.000		-		0.000	0	1.635	0
Advanced Scanning Technology for Imaging Radars (ASTIR)	C/Various	Various : Various	-	0.000		0.000		0.350		-		0.350	Continuing	Continuing	Continuing
Small Satellite Sensors	C/Various	Various : Various	-	0.000		0.250		0.737		-		0.737	Continuing	Continuing	Continuing
Seeker Cost Transformation (SECTR)*	C/Various	Various : Various	-	0.000		0.969		0.741		-		0.741	Continuing	Continuing	Continuing
Multifunction RF (MFRF)	C/Various	Various : Various	-	0.437		0.533		0.000		-		0.000	0	0.970	0
Video-rate Synthetic Aperture Radar (ViSAR)	C/Various	Various : Various	-	0.000		0.831		0.000		-		0.000	0	0.831	0

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>				Project (Number/Name) SEN-02 / <i>SENSORS AND PROCESSING SYSTEMS</i>					

Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Military Imaging and Surveillance Technology (MIST)	SS/CPFF	LEIDOS,INC. : OH	-	0.000		0.440		0.000		-		0.000	0	0.440	0
Subtotal			-	2.529		3.463		3.149		-		3.149	-	-	-

Management Services (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Management Support	C/Various	Various : Various	-	5.766		5.820		7.287		-		7.287	Continuing	Continuing	Continuing
Subtotal			-	5.766		5.820		7.287		-		7.287	-	-	-

			Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	Cost To Complete	Total Cost	Target Value of Contract
Project Cost Totals			-	115.315	116.396	145.732	-	145.732	-	-	-

Remarks

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency

Date: February 2016

Appropriation/Budget Activity

0400 / 3

R-1 Program Element (Number/Name)

PE 0603767E / SENSOR TECHNOLOGY

Project (Number/Name)

SEN-02 / SENSORS AND PROCESSING SYSTEMS

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Adaptive Radar Countermeasures																												
Develop Adaptive Radar Threat models for use in testing																												
Refine and integrate component algorithms for end-to-end system testing in simulation																												
Port software algorithms onto transition platform baseline EW systems																												
Demonstrate real-time prototype systems in hardware-in-the-loop laboratory environment																												
Complete realtime software and firmware implementation of major algorithm modules on transition plan																												
Spatial, Temporal and Orientation Information for Contested Environments (STOIC)																												
System concept design and analysis																												
Optical clock design and development																												
Optical clock lab verification and validation																												
Navigation system demonstration																												
Automatic Target Recognition (ATR) Technology																												
Design experiment and conduct data collection for baseline algorithm assessment																												
Design experiment and conduct data collection for adaptive algorithm assessment																												
Conduct baseline algorithm assessment																												
Evaluate algorithm adaptability																												

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency

Date: February 2016

Appropriation/Budget Activity

0400 / 3

R-1 Program Element (Number/Name)

PE 0603767E / SENSOR TECHNOLOGY

Project (Number/Name)

SEN-02 / SENSORS AND PROCESSING SYSTEMS

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Design experiment and conduct data collection for counter decoy assessment																												
Conduct Preliminary Design Review (PDR)																												
Evaluate algorithm ability to counter decoys																												
Advanced Scanning Technology for Imaging Radars (ASTIR)																												
Program Initiation																												
Mission application studies																												
Prototype development																												
Military application assessments																												
Small Satellite Sensors																												
Program initiation																												
Preliminary design review																												
Final design review																												
Assembly, integration and testing																												
Seeker Cost Transformation (SECTR)																												
Program Initiation																												
Hardware-in-the-loop system testing																												
Laboratory demonstrations																												
Critical design review																												
Unbanded Spectrum operations (U-SPIN)																												
Program initiation																												
Initiate algorithmic study of techniques that achieve multiple spectrum operations																												
Dynamically Composed RF Systems																												
Program initiation																												

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency																				Date: February 2016								
Appropriation/Budget Activity										R-1 Program Element (Number/Name)								Project (Number/Name)										
0400 / 3										PE 0603767E / SENSOR TECHNOLOGY								SEN-02 / SENSORS AND PROCESSING SYSTEMS										
	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Software development																												
Multifunction RF (MFRF)																												
Test platform modifications																												
Tower demonstration of prototype sensor																												
Prototype flight demonstrations																												
Video-rate Synthetic Aperture Radar (ViSAR)																												
Prototype high power amplifier development and testing																												
Integrate phenomenology data																												
Integrate components in gimbal in laboratory																												
Conduct flight tests																												
Military Imaging and Surveillance Technology (MIST)																												
Ground demonstrations of moderate range imaging system capability																												
Demonstrations of short-range imaging system																												
Mountain-to-ground demonstrations of moderate range imaging system																												
Behavioral Learning for Adaptive Electronic Warfare (BLADE)																												
Test & evaluate ground-based & airborne prototype system in an operationally relevant environment																												
Quantify minimum hardware requirements to execute the BLADE algorithms on transition platforms																												

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency																							Date: February 2016														
Appropriation/Budget Activity 0400 / 3										R-1 Program Element (Number/Name) PE 0603767E / SENSOR TECHNOLOGY								Project (Number/Name) SEN-02 / SENSORS AND PROCESSING SYSTEMS																			
										FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
										1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Conduct airborne demonstration against tactically relevant threats																																					
Transition BLADE to US Army CERDEC I2WD																																					

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency			Date: February 2016
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>	Project (Number/Name) SEN-02 / <i>SENSORS AND PROCESSING SYSTEMS</i>	

Schedule Details

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
<i>Adaptive Radar Countermeasures</i>				
Develop Adaptive Radar Threat models for use in testing	1	2015	4	2015
Refine and integrate component algorithms for end-to-end system testing in simulation	3	2015	3	2016
Port software algorithms onto transition platform baseline EW systems	3	2015	3	2015
Demonstrate real-time prototype systems in hardware-in-the-loop laboratory environment	4	2015	4	2016
Complete realtime software and firmware implementation of major algortihm modules on transition plan	3	2016	1	2017
<i>Spatial, Temporal and Orientation Information for Contested Environments (STOIC)</i>				
System concept design and analysis	4	2015	3	2016
Optical clock design and development	4	2015	2	2016
Optical clock lab verification and validation	4	2016	4	2017
Navigation system demonstration	4	2017	4	2017
<i>Automatic Target Recognition (ATR) Technology</i>				
Design experiment and conduct data collection for baseline algorithm assessment	3	2015	3	2015
Design experiment and conduct data collection for adaptive algorithm assessment	3	2015	3	2015
Conduct baseline algorithm assessment	2	2016	2	2016
Evaluate algorithm adaptability	1	2017	1	2017
Design experiment and conduct data collection for counter decoy assessment	1	2017	1	2017
Conduct Preliminary Design Review (PDR)	2	2017	2	2017
Evaluate algorithm ability to counter decoys	3	2017	3	2017
<i>Advanced Scanning Technology for Imaging Radars (ASTIR)</i>				

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency

Date: February 2016

Appropriation/Budget Activity

0400 / 3

R-1 Program Element (Number/Name)

PE 0603767E / SENSOR TECHNOLOGY

Project (Number/Name)

SEN-02 / SENSORS AND PROCESSING SYSTEMS

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
Program Initiation	1	2016	1	2016
Mission application studies	1	2016	1	2016
Prototype development	1	2016	3	2017
Military application assessments	4	2017	4	2017
Small Satellite Sensors				
Program initiation	1	2016	1	2016
Preliminary design review	2	2016	3	2016
Final design review	3	2016	1	2017
Assembly, integration and testing	1	2017	4	2017
Seeker Cost Transformation (SECTR)				
Program Initiation	1	2016	1	2016
Hardware-in-the-loop system testing	3	2016	4	2016
Laboratory demonstrations	2	2017	3	2017
Critical design review	3	2017	4	2017
Unbanded Spectrum operatioNs (U-SPIN)				
Program initiation	1	2017	1	2017
Initiate algorithmic study of techniques that achieve multiple spectrum operations	1	2017	1	2017
Dynamically Composed RF Systems				
Program initiation	1	2017	1	2017
Software development	2	2017	2	2017
Multifunction RF (MFRF)				
Test platform modifications	4	2015	4	2015
Tower demonstration of prototype sensor	4	2016	4	2016
Prototype flight demonstrations	4	2016	4	2016
Video-rate Synthetic Aperture Radar (ViSAR)				

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency **Date:** February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>	Project (Number/Name) SEN-02 / <i>SENSORS AND PROCESSING SYSTEMS</i>

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
Prototype high power amplifier development and testing	1	2015	3	2015
Integrate phenomenology data	4	2015	4	2015
Integrate components in gimbal in laboratory	2	2016	3	2016
Conduct flight tests	4	2016	4	2016
<i>Military Imaging and Surveillance Technology (MIST)</i>				
Ground demonstrations of moderate range imaging system capability	3	2015	4	2015
Demonstrations of short-range imaging system	4	2016	4	2016
Mountain-to-ground demonstrations of moderate range imaging system	4	2016	4	2016
<i>Behavioral Learning for Adaptive Electronic Warfare (BLADE)</i>				
Test & evaluate ground-based & airborne prototype system in an operationally relevant environment	2	2015	4	2015
Quantify minimum hardware requirements to execute the BLADE algorithms on transition platforms	4	2015	4	2015
Conduct airborne demonstration against tactically relevant threats	4	2015	4	2015
Transition BLADE to US Army CERDEC I2WD	4	2015	4	2015

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603767E / SENSOR TECHNOLOGY				Project (Number/Name) SEN-03 / EXPLOITATION SYSTEMS			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
SEN-03: EXPLOITATION SYSTEMS	-	48.924	13.411	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-

A. Mission Description and Budget Item Justification

The Exploitation Systems project develops algorithms, software, and information processing systems to extract information from massive intelligence, surveillance, and reconnaissance (ISR) datasets. In particular, it develops new technologies for detection and discrimination of targets from clutter, classification and fingerprinting of high value targets, localization and tracking over wide areas, and threat network identification and analysis. Interest extends to open source information and issues such as trustworthiness and provenance. The resulting technology will enable operators to more effectively and efficiently incorporate all sources of information, including sensor, human, and open source data, in intelligence products.

B. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Insight Description: Insight is developing the next generation multi-intelligence exploitation and analysis system. Insight provides new exploitation capabilities through an integrated, standards-based system that is designed for mission flexibility and cross-theater applicability. Insight will enable threat detection through combination and analysis of information from imaging and non-imaging sensors and other sources. The technical approach emphasizes graph-based correlation, adversary behavior modeling, threat network analysis tools, a unified data management and processing environment, novel exploitation algorithms and analysis methodologies, and tools to integrate human and machine processing, including visualization, hypothesis manipulation, and on-line learning. Insight development activities leverage both virtual and physical test bed environments. The virtual test bed enables evaluation of alternative sensor mixes and algorithms under extended operating conditions. The physical test bed enables live testing under realistic operational conditions using current and next generation sensing and processing systems. Insight technology development is coordinated with the following transition sponsors: Army Program Executive Office - Intelligence, Electronic Warfare & Sensors, United States Army Intelligence Center of Excellence, Project Manager Distributed Common Ground System - Army, Air Staff, National Air and Space Intelligence Center, and Air Force Research Laboratory. Insight provides a unified architecture for plug-and-play ISR with extensibility to all Services and Combatant Commands. FY 2015 Accomplishments: - Completed initial software deliveries and transferred fusion and analytic technology to the Army and Air Force. - Adapted capabilities to emerging operational environments, including integration of additional non-traditional sensors and information sources. - Tested and matured advanced fusion and analytic technologies in live and virtual environments. - Executed a live field test in coordination with a military training rotation to demonstrate improvements and maturity of system capabilities in a dynamic operational environment. - Developed a new and advanced data model compatible with existing system data models.	48.924	13.411	-

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>	Project (Number/Name) SEN-03 / <i>EXPLOITATION SYSTEMS</i>	
B. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Delivered refined, advanced and integrated capabilities to transition partner programs of record that address key performance parameters and are aligned with their software release cycles. <i>FY 2016 Plans:</i> - Test advanced fusion and analytic technologies, and demonstrate improvements and maturity of multi-intelligence exploitation capabilities. - Tailor final component and system level capabilities to specific transition partner objectives. - Deliver final integrated capabilities that address key performance parameters required by transition partner programs of record for insertion into software baselines. - Prepare and finalize software packages and documentation for transition to Services.			
Accomplishments/Planned Programs Subtotals		48.924	13.411
C. Other Program Funding Summary (\$ in Millions)			
N/A			
Remarks			
D. Acquisition Strategy			
N/A			
E. Performance Metrics			
Specific programmatic performance metrics are listed above in the program accomplishments and plans section.			

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Exhibit R-3, RDT&E Project Cost Analysis: PB 2017 Defense Advanced Research Projects Agency												Date: February 2016			
Appropriation/Budget Activity 0400 / 3						R-1 Program Element (Number/Name) PE 0603767E / SENSOR TECHNOLOGY				Project (Number/Name) SEN-03 / EXPLOITATION SYSTEMS					
Product Development (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Insight	C/CPFF	BAE : MA	-	27.008	Oct 2014	0.000		0.000		-		0.000	0	27.008	0
Insight	C/Various	Various : Various	-	15.014		11.283		0.000		-		0.000	0	26.297	0
Subtotal			-	42.022		11.283		0.000		-		0.000	0.000	53.305	0.000
Support (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Insight	MIPR	Various : Various	-	1.956		0.536		0.000		-		0.000	0	2.492	0
Subtotal			-	1.956		0.536		0.000		-		0.000	0.000	2.492	0.000
Test and Evaluation (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Insight	C/Various	Various : Various	-	2.500		0.921		0.000		-		0.000	0	3.421	0
Subtotal			-	2.500		0.921		0.000		-		0.000	0.000	3.421	0.000
Management Services (\$ in Millions)				FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total			
Cost Category Item	Contract Method & Type	Performing Activity & Location	Prior Years	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Award Date	Cost	Cost To Complete	Total Cost	Target Value of Contract
Insight	C/CPFF	Various : Various	-	2.446		0.671		0.000		-		0.000	0	3.117	0
Subtotal			-	2.446		0.671		0.000		-		0.000	0.000	3.117	0.000
			Prior Years	FY 2015		FY 2016		FY 2017 Base		FY 2017 OCO		FY 2017 Total	Cost To Complete	Total Cost	Target Value of Contract
Project Cost Totals			-	48.924		13.411		0.000		-		0.000	0.000	62.335	0.000
Remarks															

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Exhibit R-4, RDT&E Schedule Profile: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>	Project (Number/Name) SEN-03 / <i>EXPLOITATION SYSTEMS</i>

	FY 2015				FY 2016				FY 2017				FY 2018				FY 2019				FY 2020				FY 2021			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Insight																												
Delivery of Insight System to Army I2WD in support of MOA																												
Field Test 5 at National Training Center, Ft Irwin, CA																												
Delivery to National Air and Space Intelligence Center																												
Deliveries to additional transition partners																												

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Exhibit R-4A, RDT&E Schedule Details: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>	Project (Number/Name) SEN-03 / <i>EXPLOITATION SYSTEMS</i>

Schedule Details

Events by Sub Project	Start		End	
	Quarter	Year	Quarter	Year
<i>Insight</i>				
Delivery of Insight System to Army I2WD in support of MOA	1	2015	1	2016
Field Test 5 at National Training Center, Ft Irwin, CA	1	2015	4	2015
Delivery to National Air and Space Intelligence Center	3	2015	1	2016
Deliveries to additional transition partners	4	2015	4	2016

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Exhibit R-2A, RDT&E Project Justification: PB 2017 Defense Advanced Research Projects Agency										Date: February 2016		
Appropriation/Budget Activity 0400 / 3					R-1 Program Element (Number/Name) PE 0603767E / <i>SENSOR TECHNOLOGY</i>				Project (Number/Name) SEN-06 / <i>SENSOR TECHNOLOGY</i>			
COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
SEN-06: <i>SENSOR TECHNOLOGY</i>	-	87.400	92.199	76.529	-	76.529	46.800	17.875	5.000	0.000	-	-
A. Mission Description and Budget Item Justification This project funds classified DARPA programs that are reported in accordance with Title 10, United States Code, Section 119(a)(1) in the Special Access Program Annual Report to Congress.												
B. Accomplishments/Planned Programs (\$ in Millions)										FY 2015	FY 2016	FY 2017
Title: Classified DARPA Program Description: This project funds Classified DARPA Programs. Details of this submission are classified. FY 2015 Accomplishments: Details will be provided under separate cover. FY 2016 Plans: Details will be provided under separate cover. FY 2017 Plans: Details will be provided under separate cover.										87.400	92.199	76.529
Accomplishments/Planned Programs Subtotals										87.400	92.199	76.529
C. Other Program Funding Summary (\$ in Millions) N/A Remarks D. Acquisition Strategy N/A E. Performance Metrics Details will be provided under separate cover.												

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 6:</i> <i>RDT&E Management Support</i>	R-1 Program Element (Number/Name) PE 0605001E / <i>MISSION SUPPORT</i>

COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	0.000	0.000	69.244	-	69.244	71.293	72.930	73.134	72.995	-	-
MST-01: <i>MISSION SUPPORT</i>	-	0.000	0.000	69.244	-	69.244	71.293	72.930	73.134	72.995	-	-
Quantity of RDT&E Articles	-	-	-	-	-	-	-	-	-	-		

A. Mission Description and Budget Item Justification

This program element is budgeted in the Management Support Budget Activity because it provides funding for the costs of mission support activities for the Defense Advanced Research Projects Agency. The funds provide personnel compensation for mission support civilians as well as costs for building rent, physical security, travel, supplies and equipment, communications, printing and reproduction. Mission support administrative costs were previously budgeted in PE 0605898E, Project MH-01.

<u>B. Program Change Summary (\$ in Millions)</u>	<u>FY 2015</u>	<u>FY 2016</u>	<u>FY 2017 Base</u>	<u>FY 2017 OCO</u>	<u>FY 2017 Total</u>
Previous President's Budget	0.000	0.000	0.000	-	0.000
Current President's Budget	0.000	0.000	69.244	-	69.244
Total Adjustments	0.000	0.000	69.244	-	69.244
• Congressional General Reductions	0.000	0.000			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	0.000	0.000			
• SBIR/STTR Transfer	0.000	0.000			
• TotalOtherAdjustments	-	-	69.244	-	69.244

Change Summary Explanation

FY 2015: N/A

FY 2016: N/A

FY 2017: Increase reflects Departmental implementation of congressional direction.

<u>C. Accomplishments/Planned Programs (\$ in Millions)</u>	<u>FY 2015</u>	<u>FY 2016</u>	<u>FY 2017</u>
<i>Title:</i> Mission Support	-	-	69.244
<i>Description:</i> Mission Support			
<i>FY 2017 Plans:</i>			

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016	
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide I</i> BA 6: <i>RDT&E Management Support</i>		R-1 Program Element (Number/Name) PE 0605001E / <i>MISSION SUPPORT</i>	
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016
- Fund mission support civilian salaries and benefits, and administrative support costs. - Fund travel, rent and other infrastructure support costs. - Fund security costs to continue access controls, uniformed guards, and building security requirements. - Fund CFO Act compliance costs.			
Accomplishments/Planned Programs Subtotals		-	69.244
D. Other Program Funding Summary (\$ in Millions)			
N/A			
Remarks			
E. Acquisition Strategy			
N/A			
F. Performance Metrics			
N/A			

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: Research, Development, Test & Evaluation, Defense-Wide / BA 6: RDT&E Management Support	R-1 Program Element (Number/Name) PE 0605502E / SMALL BUSINESS INNOVATION RESEARCH

COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	85.266	0.000	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-
SB-01: SMALL BUSINESS INNOVATION RESEARCH	-	85.266	0.000	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-
Quantity of RDT&E Articles	-	-	-	-	-	-	-	-	-	-		

A. Mission Description and Budget Item Justification

In accordance with Public Law No: 112-81 (National Defense Authorization Act) and Small Business Technology Transfer Program Reauthorization Act, the DARPA Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs are designed to provide small, high-tech businesses and academic institutions the opportunity to propose radical, innovative, high-risk approaches to address existing and emerging national security threats; thereby supporting DARPA's overall strategy to enable fundamental discoveries and technological breakthroughs that provide new military capabilities.

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	0.000	0.000	0.000	-	0.000
Current President's Budget	85.266	0.000	0.000	-	0.000
Total Adjustments	85.266	0.000	0.000	-	0.000
• Congressional General Reductions	0.000	0.000			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	0.000	0.000			
• SBIR/STTR Transfer	85.266	0.000			

Change Summary Explanation

FY 2015: Increase reflects the SBIR/STTR transfer.
 FY 2016: N/A
 FY 2017: N/A

C. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Small Business Innovation Research	85.266	-	-
Description: The Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs are			

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide I</i> BA 6: <i>RDT&E Management Support</i>		R-1 Program Element (Number/Name) PE 0605502E / <i>SMALL BUSINESS INNOVATION RESEARCH</i>		
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
designed to provide small, high-tech businesses and academic institutions the opportunity to propose radical, innovative, high-risk approaches to address existing and emerging national security threats; thereby supporting DARPA's overall strategy to enable fundamental discoveries and technological breakthroughs that provide new military capabilities.				
FY 2015 Accomplishments: - The DARPA SBIR and STTR were executed within OSD guidelines.				
Accomplishments/Planned Programs Subtotals		85.266	-	-
D. Other Program Funding Summary (\$ in Millions) N/A				
Remarks				
E. Acquisition Strategy N/A				
F. Performance Metrics Not applicable.				

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency	Date: February 2016

Appropriation/Budget Activity 0400: Research, Development, Test & Evaluation, Defense-Wide / BA 6: RDT&E Management Support	R-1 Program Element (Number/Name) PE 0605898E / MANAGEMENT HQ - R&D

COST (\$ in Millions)	Prior Years	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total	FY 2018	FY 2019	FY 2020	FY 2021	Cost To Complete	Total Cost
Total Program Element	-	71.362	71.571	4.759	-	4.759	4.835	4.449	4.300	4.389	-	-
MH-01: MANAGEMENT HQ - R&D	-	71.362	71.571	4.759	-	4.759	4.835	4.449	4.300	4.389	-	-
Quantity of RDT&E Articles	-	-	-	-	-	-	-	-	-	-		

A. Mission Description and Budget Item Justification

This program element is budgeted in the Management Support Budget Activity because it provides funding for the administrative support costs of the Defense Advanced Research Projects Agency. In FY 2015 and FY 2016, the PE funds personnel compensation for civilians as well as costs for building rent, physical security, travel, supplies and equipment, communications, printing and reproduction. Beginning in FY 2017, this project provides funding for the Management Headquarters Activities (MHA) of DARPA only. The funds provide personnel compensation for management headquarters civilians as well as associated travel costs. Mission support costs are reflected in PE 0605001E, Project MST-01.

B. Program Change Summary (\$ in Millions)	FY 2015	FY 2016	FY 2017 Base	FY 2017 OCO	FY 2017 Total
Previous President's Budget	71.362	71.571	73.539	-	73.539
Current President's Budget	71.362	71.571	4.759	-	4.759
Total Adjustments	0.000	0.000	-68.780	-	-68.780
• Congressional General Reductions	0.000	0.000			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	0.000	0.000			
• SBIR/STTR Transfer	0.000	0.000			
• TotalOtherAdjustments	-	-	-68.780	-	-68.780

Change Summary Explanation

FY 2015: N/A

FY 2016: N/A

FY 2017: Decrease reflects Departmental implementation of congressional direction.

C. Accomplishments/Planned Programs (\$ in Millions)

	FY 2015	FY 2016	FY 2017
Title: Management Headquarters	71.362	71.571	4.759

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Exhibit R-2, RDT&E Budget Item Justification: PB 2017 Defense Advanced Research Projects Agency		Date: February 2016		
Appropriation/Budget Activity 0400: <i>Research, Development, Test & Evaluation, Defense-Wide / BA 6: RDT&E Management Support</i>	R-1 Program Element (Number/Name) PE 0605898E / <i>MANAGEMENT HQ - R&D</i>			
C. Accomplishments/Planned Programs (\$ in Millions)		FY 2015	FY 2016	FY 2017
Description: Management Headquarters FY 2015 Accomplishments: - Funded civilian salaries and benefits, and administrative support costs. - Funded travel, rent and other infrastructure support costs. - Funded security costs to continue access controls, uniformed guards, and building security requirements. - Funded CFO Act compliance costs. FY 2016 Plans: - Fund civilian salaries and benefits, and administrative support costs. - Fund travel, rent and other infrastructure support costs. - Fund security costs to continue access controls, uniformed guards, and building security requirements. - Fund CFO Act compliance costs. FY 2017 Plans: - Fund management headquarters civilian salaries, benefits, and travel costs.				
Accomplishments/Planned Programs Subtotals		71.362	71.571	4.759
D. Other Program Funding Summary (\$ in Millions) N/A Remarks E. Acquisition Strategy N/A F. Performance Metrics Specific programmatic performance metrics are listed above in the program accomplishments and plans section.				

Basic Neuroscience
Review

DARPA-funded efforts in the development of novel brain–computer interface technologies



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H I G H L I G H T S

- DARPA's programs foster multi-disciplinary collaborations.
- DARPA's BCI programs span four major challenges: detect, emulate, restore, & improve.
- Aims: restore function after injury; improve performance of healthy individuals.

A R T I C L E I N F O

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A B S T R A C T

The Defense Advanced Research Projects Agency (DARPA) has funded innovative scientific research and technology developments in the field of brain–computer interfaces (BCI) since the 1970s. This review highlights some of DARPA's major advances in the field of BCI, particularly those made in recent years. Two broad categories of DARPA programs are presented with respect to the ultimate goals of supporting the nation's warfighters: (1) BCI efforts aimed at restoring neural and/or behavioral function, and (2) BCI efforts aimed at improving human training and performance. The programs discussed are synergistic and complementary to one another, and, moreover, promote interdisciplinary collaborations among researchers, engineers, and clinicians. Finally, this review includes a summary of some of the remaining challenges for the field of BCI, as well as the goals of new DARPA efforts in this domain.

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Contents

1. Introduction	53
2. DARPA BCI efforts to restore neural and behavioral function.....	54
2.1. Revolutionizing Prosthetics	54
2.2. Reorganization and Plasticity to Accelerate Injury Recovery (REPAIR).....	56

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2.3.	Co-adaptive BCI for restoration of sensorimotor function	57
2.4.	Restorative Encoding Memory Integration Neural Device (<i>REMIND</i>)	58
2.5.	Reliable Neural Interface Technology (<i>RE-NET</i>)	59
3.	DARPA BCI efforts to improve human training and performance	60
3.1.	Accelerated Learning	60
3.2.	Narrative Networks (<i>N2</i>)	61
3.3.	Neurotechnology for Intelligence Analysts (<i>NIA</i>)	61
3.4.	Cognitive Technology Threat Warning System (<i>CT2WS</i>)	62
3.5.	Low-cost EEG Technologies	64
4.	Future efforts and challenges for brain–computer interface technologies	64
	Disclaimer	65
	Public release statement	65
	References	65

1. Introduction

Brain–computer interfaces (BCI) are systems that mediate signaling between the brain and various technological devices. The first demonstrations of BCI in humans and animals took place in the 1960s. In 1964, Grey Walter demonstrated use of non-invasively recorded encephalogram (EEG) signals from a human subject to control a slide projector (Graumann et al., 2010). Shortly thereafter, Fetz demonstrated that, by providing food reward to awake, non-human primates along with auditory or visual feedback on the firing rates of neurons in the motor cortex, these neurons could be operantly conditioned to increase their firing rates by 50–500% (Fetz, 1969). In 1971 the term brain–computer interface (BCI) was coined by Jacques J. Vidal, who laid out a comprehensive experimental research plan to interface the human brain with computers (Vidal, 1973), including the XDS Sigma 7 at the University of California at Los Angeles that coincidentally also served as the first node of the Advanced Research Projects Agency Network (ARPANET). Following these initial demonstrations, the field of BCI has expanded significantly, encompassing both invasive and non-invasive neural recordings in humans and animals, spanning a range of sensorimotor and cognitive functions, and incorporating novel feedback mechanisms in closed-loop systems.

While most closed-loop BCI systems provide feedback to the user on system performance through the presentation of sensory (primarily visual) information, approaches have also been developed to provide sensory feedback through direct stimulation of the nervous system. For instance, unidirectional systems such as cochlear and retinal implants can provide partial restoration of sight and hearing through the direct stimulation of neurons within the cochlea and retina, respectively (see Géléoc and Holt, 2014; Chuang et al., 2014 for review). Recent explorations of targeted reinnervation in amputees suggest that such approaches may not only enable prosthetic limb control through peripheral nerve signals but may also provide a means of conveying somatosensory sensation of touch, temperature, pain, and vibration to these patients (Hebert et al., 2013).

Sensory percepts can also be elicited through direct brain stimulation (Schiller et al., 2011; Kar and Krekelberg, 2012; Larson and Cheung, 2012; Tabot et al., 2013; Zaaimi et al., 2013; May et al., 2013; Johnson et al., 2013). Such findings provide a proof of concept for the integration of stimulation-induced sensory feedback into BCI systems as a novel mechanism of closing the loop (e.g., see O'Doherty et al., 2011). In addition to providing an alternative means of sensory perception, direct brain stimulation can also be used to bridge the gap across perturbed neural connections (Berger et al., 2011). Studies suggest that neural stimulation may even have the potential to restore functional connectivity and associated behaviors through modulation of molecular mechanisms of synaptic efficacy (Jacobs et al., 2012; Rahman et al., 2013; Song et al.,

2013). In this regard, BCI technologies may not only be useful for *enabling* function, but also have the potential for implementation as a therapeutic device for *restoring* function.

A primary application of BCI is to provide a mechanism for movement or communication by patients who are unable to move or communicate through normal pathways. Such approaches have included the translation of recorded neural signals associated with sensory and goal-directed mechanisms into navigation or selection commands, enabling the user to move through a virtual or real environment or to select letters to type for purposes of communication (Thurlings et al., 2010). Other approaches have included decoding of neural signals directly associated with the intent to move (Collinger et al., 2013; Doud et al., 2011) or speak (Pei et al., 2011). In addition to approaches that leverage correlates of user intent, BCI has been utilized to provide neurofeedback to users, enabling them to regulate neural and behavioral functions normally not under volitional control. Such functions include attention, pain, emotion, and memory (Birbaumer et al., 2009).

While people living with injury remain a primary end-user target population for the field of BCI, the increasing availability of portable hardware for real-time non-invasive sensing of neural activity has also led to the development of commercial BCI applications for healthy individuals, as seen by recent incorporation of BCI within the gaming industry. BCI games have used neural signals to control or influence functions such as steering through virtual environments, changing the form and function of avatars, or controlling the movement of a virtual ball through collaboration or competition among multiple users (for review, see Coyle et al., 2013; Marshall et al., 2013).

Recent advances in the field of BCI have been achieved via a broad spectrum of funding sources across academic, industry, clinical, and various international government organizations. The current review, however, is focused on BCI research funded by the Defense Advanced Research Projects Agency (DARPA). Established in 1958 in response to the Soviet launch of the world's first satellite, Sputnik, DARPA's mission is to maintain technological superiority of the United States military and prevent technological surprise by U.S. adversaries (Defense Advanced Research Projects Agency, 2013). To achieve this mission, DARPA invests in revolutionary, high-risk/high-reward research efforts ranging from fundamental scientific discoveries to the application of these discoveries for military use. DARPA's primary constituents are the military services and American warfighters. The agency's goal is to provide these constituents with the capabilities to perform their complex duties and to quickly and effectively recover from adverse events.

While DARPA itself does not conduct scientific research, the agency's program managers and directors, whose expertise spans diverse scientific and military fields, are highly immersed in the scientific research community as well as the U.S. military community. Through interactions with these communities,

DARPA assesses current needs and state-of-the-art scientific and technological achievements and identifies areas in which groundbreaking advances could revolutionize national security capabilities. Through its programs, DARPA funds research and development efforts conducted by a broad spectrum of industry, academic, and other government organizations. These efforts range from fundamental scientific exploration to development of prototype technological devices with specific end-user applications. Additionally, DARPA facilitates transition and operationalization of successful results from its programs for military and commercial use.

In recent years, DARPA has supported highly innovative research in the field of neuroscience, fostering multi-disciplinary collaborations among neurobiologists, neuropsychologists, mathematicians, and engineers. The goals of these efforts span four major challenges:

- *Detect* – Develop diagnostics, models, and devices to characterize and mitigate threats to the human brain.
- *Emulate* – Leverage inspiration from functional brain networks to efficiently synthesize information.
- *Restore* – Reestablish behavioral and cognitive function lost as a result of injury to the brain or body.
- *Improve* – Develop brain-in-the-loop systems to accelerate training and improve functional behaviors.

Of relevance to this special issue, many of DARPA's investments in neuroscience have encompassed the development of novel BCI technologies. These DARPA-funded efforts have enabled new neural interface technologies for detecting multi-scale and multi-region brain function in real time, as well as complex mathematical algorithms that emulate the translation of neural activity into activity in downstream brain areas and resulting behavioral functions. Together, these neural interfaces and mathematical models are integrated into BCI systems that can restore and/or facilitate near-natural neural and behavioral function.

DARPA's initial investments in BCI began in 1974 under the *Close-Coupled Man/Machine Systems* (later renamed *Biocybernetics*) program. This program investigated the application of human physiological signals, including brain signals as measured non-invasively using either EEG or magnetoencephalography (MEG), to enable direct communication between humans and machines and to monitor neural states associated with vigilance, fatigue, emotions, decision-making, perception, and general cognitive ability. The program yielded notable advancements, such as detailed understanding of single-trial, sensory-evoked responses in the EEG of human participants. These efforts demonstrated that neural activity in response to visual checkerboard stimuli, alternating at different frequencies at each of four fixation points, could be decoded in real time and used to navigate a cursor through a simple maze (Vidal, 1977). In 2002 DARPA took a deeper dive into the field of BCI by launching its *Brain Machine Interface (BMI)* program, shortly followed by the *Human Assisted Neural Devices (HAND)* program. These early programs tackled a wide array of BCI challenges including sensorimotor control of prosthetic devices (Carmena et al., 2003), facilitation of memory encoding (Song et al., 2007), decoding of visual inputs (Hung et al., 2005), development of dynamic neural decoding algorithms (Gage et al., 2005), as well as the development of new devices for high-resolution neural imaging (Vetter et al., 2004). These DARPA-funded efforts provided many of the foundational discoveries and technologies that have enabled more recent developments in this field.

This review highlights several recent and ongoing DARPA-funded programs that are aimed at utilizing BCI to either restore neural and behavioral function following injury to the brain, or to improve human performance through intervention during training or operational tasks. Notably, under President Obama's

Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative, announced in April 2013, DARPA is currently supporting new research efforts aimed at the development of novel BCI technologies for restoring function in human clinical populations with either neuropsychiatric or memory dysfunction. The goals of these new programs will be described further in the conclusion of this review.

2. DARPA BCI efforts to restore neural and behavioral function

Recent and ongoing DARPA programs supporting the development of BCI technologies to restore neural and behavioral function include *Revolutionizing Prosthetics*, *Reorganization and Plasticity to Accelerate Injury Recovery (REPAIR)*, *Restorative Encoding Memory Integration Neural Device (REMIND)*, and *Reliable Neural Interface Technology (RE-NET)*. These programs are complementary and synergistic, leveraging novel techniques to interface with the nervous system, providing new fundamental approaches to modeling the nervous system, and enabling direct communication with the brain, body, and environment. For the application of actuation, *Revolutionizing Prosthetics* is translating state-of-the-art BCI systems to restore sensorimotor function in humans, and *REPAIR* is utilizing animal models to advance neural decoder capabilities through the incorporation of multi-scale, dynamic models that account for the brain's plastic changes underlying sensorimotor function during learning or following injury. The BCI system developed by the *REMIND* program targets a different neurobehavioral system – memory – and has demonstrated the improvement and restoration of performance on memory tasks in animal models. Finally, the *RE-NET* program is addressing challenges involved in developing safe, robust BCI systems for chronic use and is applicable to a broad spectrum of BCI applications.

2.1. Revolutionizing Prosthetics

The *Revolutionizing Prosthetics* program began in 2006 with the vision of restoring near-natural dexterity for people with loss of upper-limb control. The objective was to allow Wounded Warrior amputees to improve quality of life, maximize function and independence, enable activities of daily living, and return to service (if desired). DARPA embarked on this challenge in response to the increased incidence of amputations and injuries to the nervous system suffered by service members. Major upper extremity disabilities are a significant problem for the Department of Defense (DoD). Between 2000 and 2011, there were nearly 6000 amputations of service members within the US Armed Forces, with over two-thirds of these instances involving upper extremity amputations (O'Donnell, 2012). Approximately 16.5% of amputees returned to active duty, with return-to-duty rates of single amputees reaching 20% (Stinner et al., 2010). Therefore, there is a need for functional solutions that enable service members to deliver high performance. In addition to amputees, the *Revolutionizing Prosthetics* program also serves individuals with loss of upper extremity function as a result of spinal cord injury (SCI). It is estimated that there are nearly 300,000 individuals in the US living with SCI with approximately 12,000 new cases every year (National Spinal Cord Injury Statistical Center, 2013).

Prior to DARPA's investments in this area, there were few options for military personnel suffering with these disorders. Remarkably, one of the most commonly used solutions to upper extremity loss was the split hook prosthetic developed in 1912 (Dorrance, 1912). Evaluation of the state-of-the-art revealed that very little progress had been made in prosthetic innovation since this time with meager advances with the 1938 Becker

design (Becker, 1942), National Academy of Science Artificial Limb Program of 1945 (Furman, 1962), and the available one-degree-of-freedom (DOF) hands that were on the market in the early 2000s. DARPA responded to the lack of advanced prosthetic limb options for upper-extremity amputees with a two-pronged development strategy. Both efforts focused on developing modular arm systems that could provide support to a variety of amputees including transradial, transhumeral, as well as full shoulder disarticulation. Development of these prosthetic limbs involved highly demanding specifications that mimicked attributes and capabilities of real human arms including weight, shape, and grip strength. Two teams of investigators, DEKA and The Johns Hopkins University Applied Physics Laboratory (JHU/APL), took on the task of designing and assembling these next generation arms to meet the program demands (Johannes et al., 2011; Resnik et al., 2013). The advanced DARPA arm systems, one with ten and the other with seventeen miniature motors, enabled replication of near-natural hand and arm movements and are available to the research and clinical communities. Additionally, a virtual arm system is available for prototyping (Armiger et al., 2011; Collinger et al., 2014).

In addition to the arms themselves, the *Revolutionizing Prosthetics* program also produced innovations in the user control interface. Since the diversity in loss of upper extremity function was high among military personnel, the control interfaces had to provide multiple options such that the user could choose the solution most appropriate to their own needs, thus leading to personalized medicine. The first control interface developed under the *Revolutionizing Prosthetics* program was a non-invasive control modality that does not require surgical procedures. It consisted of inertial measurement units that could be placed on the shoes as well as pressure/bump switches that could be attached to the torso. Movement of the inertial units enabled actuation of all of the degrees of freedom while the bump switches enabled changes in the arm modes (hand grips, for example). The use of these interfaces was well received by prosthetic limb users, and over 7000 h among 77 amputees and quadriplegics have been logged during pilot testing. Other viable approaches for peripheral control of these arm systems include the electromyogram (EMG), targeted muscle reinnervation (TMR), as well as nerve interfaces such as implanted myoelectric sensors (IMES) (for a review, see Ortiz-Catalan et al., 2012). In May 2014, the DEKA arm system received U.S. Food and Drug Administration (FDA) approval. Initial input control modalities in this approval include inertial and EMG control. Efforts are ongoing to make these systems available to military and civilian personnel.

Beyond the use of inertial or EMG control, *Revolutionizing Prosthetics* has provided transformative innovations in direct brain control of prosthetic limbs that enabled human users to think about moving in much the same way they would control their own arm to actuate the prosthetic arm systems (Collinger et al., 2013). This line of research and development involved real-time recording and decoding of motor cortical signals to provide research participants with tetraplegia the ability to control up to ten DOF with the prosthetic arm systems. The main enablers for near-natural control include micro-electrode arrays for recording brain signals and complex algorithms to translate neural activity into commands for the motors throughout the prosthetic arm system. In the *Revolutionizing Prosthetics* program, single unit neuronal recordings have been achieved in a human clinical patient via the implantation of two intracortical microelectrode arrays (Blackrock Microsystems, Salt Lake City, UT), each with 96 electrode shanks. The 4 mm × 4 mm assembly was implanted in the participant's motor cortex (M1) and connected percutaneously through the use of two head-mounted pedestals. Using preoperative structural and functional MRI and magnetoencephalography (MEG) to identify hand and finger activation areas in M1 for the purpose of decoding grasp behaviors, the

arrays were implanted 14 mm apart through the use of a stereotaxic surgical navigation system (Collinger et al., 2014). The combined signals from these arrays allowed for the simultaneous recording of over 250 unique single units, which were then processed in real-time to ultimately send commands to move the JHU/APL prosthetic limb. The recorded signals passed through a Blackrock Microsystems NeuroPort data acquisition system, which converted neuronal firing rate (30-ms bins) into a functional mapping for prosthetic limb commands in endpoint velocity space. Real-time visual feedback from the prosthetic limb to the participant enabled closed-loop control. Using this system, the participant achieved control of the arm in three DOF (endpoint of the wrist) within two weeks of implantation, and began operating on seven DOF within five weeks (Collinger et al., 2013). Depending on the types of signals acquired from the brain (single neuron vs. electrocorticogram (ECoG)), new population vector decoding methodologies and shared control architectures needed to be developed to allow users to initialize their control of the system and then adaptively learn to obtain increasing control of a greater number of degrees of freedom (e.g., see Collinger et al., 2013). Applying such methodologies to novel behavioral paradigms, *Revolutionizing Prosthetics* efforts have further elucidated the neural mechanisms underlying human-tool interaction. These discoveries have enabled a deeper understanding of how the brain represents motor control, environmental cues, object interaction, and perception of neuroprosthetic control (Hauschild et al., 2012; Collinger et al., 2013). Performance was established both in terms of completion of various reach and grasp tasks, and also by way of evaluation against functional metrics such as the Action Research Arm Test (ARAT), a clinical outcome measure derived from the stroke rehabilitation community (Lyle, 1981).

To continue to push the frontier of the intersection between brain science and technology and deliver the most natural arm systems, DARPA researchers have laid the foundation for adding the next generation of neuroprosthetic control by exploring the restoration of the sense of touch. Constructing closed-loop complete sensorimotor systems is essential for identifying objects, manipulating objects, and even grasping objects in the absence of vision. Some of the first steps in developing these next generation interfaces have involved investigating how the non-human primate brain encodes sensory information provided via natural means (tactile stimulation of the subject's own fingers), and comparing that to the psychometric evaluation of the encoding of sensory information delivered through cortical stimulation (Tabot et al., 2013; Zaaimi et al., 2013). These efforts explored simple percepts of touch, as well as complex encoding of slip and texture. For the *Revolutionizing Prosthetics* program, a series of experiments were performed at the University of Chicago to demonstrate safety of chronically implanted stimulating electrode arrays in the somatosensory cortex of non-human primates. The implant configuration consisted of two 100-channel, sputtered iridium oxide film (SIROF)-tipped Utah electrode arrays (UEA) connected via Cereport connectors to a CereStim R96 stimulator, all manufactured by Blackrock Microsystems. Stimulation was delivered to three non-human primates at 300 Hz across a range of charge amplitudes, duty cycles, and interval durations. Sensory stimulation was performed for 4 h per day over a period of six months. The results revealed no deficits in fine motor control and demonstrated safety of the electrode-tissue interface (Chen et al., 2014). In tandem with the safety study, an efficacy study was also performed at University of Chicago to characterize the relationship between mechanical and electrical stimulation on tactile tasks (Berg et al., 2013). Using both a 96-electrode SIROF-tipped UEA implanted in the hand representation of Brodmann's area 1 and two 16-electrode Floating Microelectrode Arrays (MicroProbes for Life Sciences, Gaithersburg, MD) targeting the hand region in Brodmann's area 3b, the implants

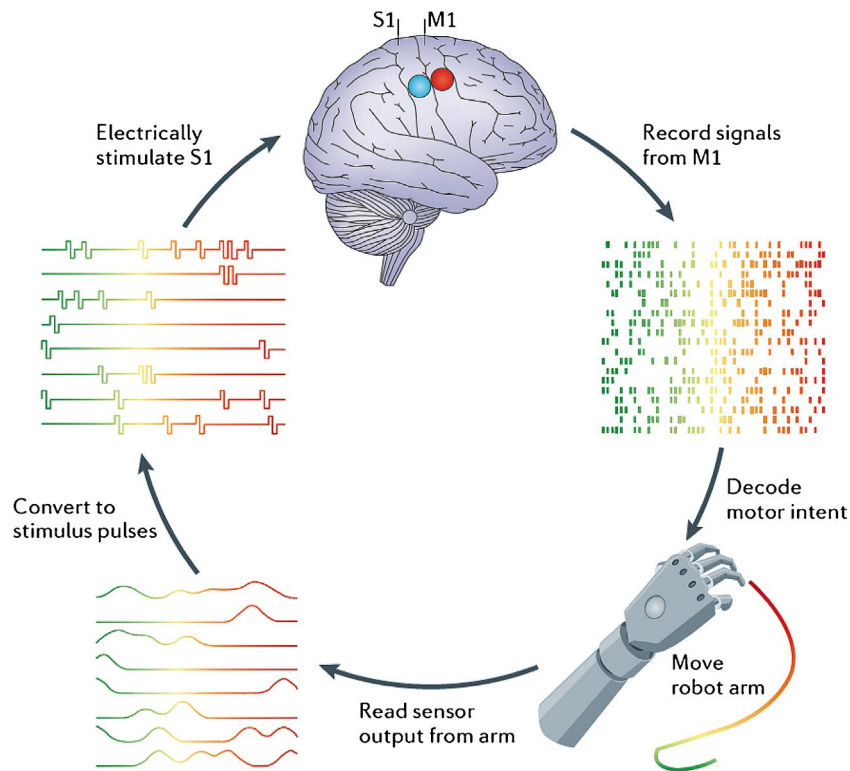


Fig. 1. Idealized bidirectional brain–computer interface for closed-loop prosthetic control. Neural correlates of motor intent are recorded from electrode arrays implanted in motor areas of the brain such as the primary motor cortex (M1). The signals are decoded and used to control the movement of a prosthetic arm. Sensors on the robotic arm detect information on touch (via contacts with external objects) and/or proprioception (via movement and position of the prosthetic limb). Outputs from these sensors are then converted to patterns of stimulus pulses that are delivered via implanted electrode arrays to sensory regions of the brain, such as primary somatosensory cortex (S1). Reprinted from “Restoring sensorimotor function through intracortical interfaces: progress and looming challenges,” by S.J. Bensmaia and L.E. Miller, 2014, *Nature Reviews Neuroscience*, 15, p. 315. Copyright 2014 by Nature Publishing Group. Reprinted with permission.

and corresponding stimulation via a CereStim stimulator were used in a series of electrical detection tasks and compared against mechanical detection tasks. It was demonstrated that electrical stimulation sent in response to tactile stimulation of the prosthetic finger showed equivalent detection performance to mechanical stimulation of the native finger, with a psychometric curve function defining the relationship between mechanical and electrical sensation for use in subsequent stimulation experiments. This combined suite of safety and efficacy data has been critical in the support of FDA Investigational Device Exemption (IDE) approval for testing in human clinical populations. The ultimate vision for transitioning these efforts for clinical use is to enable signals from sensors on prosthetic fingers to be translated into stimulation signals delivered directly to the sensory cortex, enabling patients to ‘feel’ when their prosthetic hand touches objects. This transition from visually driven closed-loop control to full sensorimotor closed-loop control (see Fig. 1) is anticipated to enable increased user control of prosthetic limbs, with faster response times and near-natural sensation during performance of tasks with occluded views or those that require tactile feedback. It is hoped that these advances will continue to improve independence and quality of life after injury in users of prosthetic limbs.

2.2. Reorganization and Plasticity to Accelerate Injury Recovery (REPAIR)

Although the BCI technologies developed under the *Revolutionizing Prosthetics* program have proved quite remarkable in enabling direct neural control of robotic limbs, the neural decoding algorithms do not capitalize on one of the brain’s fundamental characteristics – plasticity. Importantly, brain function is not fixed or

static, but rather it adapts in response to learning new information (such as meeting a new person) or new behavioral skills (such as riding a bicycle). Moreover, these learning processes are subserved by brain activity at multiple spatial scales, ranging from the activity of single neurons to coordinated patterns of activity across small and large networks of neurons, and ultimately, to behavior. Such changes also occur across multiple temporal scales, encompassing millisecond level functional changes as well as structural changes that can result in alterations in neural activity over days, weeks, months, or longer. In addition to adaptation of the brain in response to learning, the brain’s function can also be dynamically altered by injury, either of the brain itself, such as in the case of traumatic brain injury (TBI), or of the body – for instance, amputees no longer have normal sensations of touch that are sent to the brain’s sensory regions, and they can no longer use the brain’s motor control systems to directly move their affected limb (e.g., see Pohlmeier et al., 2014).

The goal of DARPA’s REPAIR program, initiated in 2010 and projected to continue through 2015, is to develop a multi-scale, biologically accurate model of neural function that accounts for the brain’s adaptation over time. The computational models developed under REPAIR have focused on sensorimotor function, that is, how the brain learns to use sensory information such as touch or vision to generate appropriate reaching and grasping behaviors in order to perform complex tasks (e.g., see Sanchez et al., 2012; Shenoy and Nurmikko, 2012; Andersen et al., 2012). Under this program, new neural interface tools have been designed to detect and alter the activity of large populations of neurons in awake, behaving non-human primates across multiple spatial and temporal scales. Neural recordings from these interfaces have been used to develop and validate computational models that emulate

dynamic functions of the brain and resulting behaviors. Through highly collaborative efforts across eight universities, the computational models developed under *REPAIR* are being integrated with one another and interfaced directly with the brain for the purpose of restoring neural and behavioral function following neural injury or sensory deprivation. The final dynamic model developed under the *REPAIR* program is anticipated to be incorporated into a co-adaptive BCI system that optimally facilitates sensorimotor function in a non-human primate by enabling adaptation of both the *in silico* model and biological brain. While research efforts conducted under *REPAIR* have utilized only animal models, the new technologies and scientific insights will undoubtedly provide a foundation for the development of novel therapeutic devices for human clinical populations.

Computational models developed under *REPAIR* include biomimetic models that mimic the properties of neuronal firing and dynamic connectivity across networks of neurons (Kerr et al., 2012). Such models have been integrated with higher-level biomimetic models of reinforcement learning that the brain undergoes while learning to perform new tasks (Mahmoudi and Sanchez, 2011; Neymotin et al., 2013). *REPAIR* researchers have also developed low-dimensional models that predict state space trajectories of population level neural activity involved in planning and execution of sensorimotor behaviors (Shenoy et al., 2013; Ames et al., 2014). Additionally, new sophisticated algorithms have been developed that decode neural representations of force related variables, such as torque, in addition to traditional kinematic variables (e.g., position), resulting in more natural sensorimotor prosthetic control and the ability to compensate for novel dynamic environments, compared to traditional decoders based on kinematic variables alone (Chhatbar and Francis, 2013). *REPAIR* investigators are developing and testing their models by recording neural activity in animals performing complex behavioral tasks, and, importantly, determining whether the models correctly predict multi-scale changes in brain activity and behavior when certain aspects of the brain's activity are temporarily perturbed. Many of these studies are investigating neural correlates of complex behaviors in freely moving non-human primates and have been made possible by recent developments in wireless neural interfaces (Foster et al., 2012; Borton et al., 2013).

To perform precise, reversible perturbations of brain activity, *REPAIR* researchers have leveraged and expanded upon recent developments in optogenetics, enabling expression of bioengineered opsins (light-sensitive channels) within the cell membranes of specific types of neurons (Diester et al., 2011; Zalocusky and Deisseroth, 2013). These opsins undergo modified configurations in response to specific wavelengths of light, altering the thresholds for neuronal action potentials, and ultimately resulting in an increase or decrease of neuronal firing activity in the presence of specific colors of light. Moreover, new neural interface hardware developed under the *REPAIR* program has enabled optical neuro-modulation simultaneous with electrical recording of single and multi-unit activity in awake, behaving non-human primates (e.g., see Fig. 2) (Shenoy and Nurmikko, 2012; Ozden et al., 2013). These new developments have been of utmost importance in the *REPAIR* program to facilitate modeling of the brain's dynamic responses to perturbations of neural activity.

In addition to reversibly perturbing brain activity to develop and validate computational models, *REPAIR* researchers have also demonstrated that direct brain stimulation can be used to substitute for missing sensory information. Dadarlat et al. demonstrated the use of intracortical electrical microstimulation (ICMS) of the non-human primate somatosensory cortex to convey the dynamic location of the animal's arm in relation to an unseen target location (Dadarlat et al., 2013). Notably, the patterns of stimulation were arbitrary (i.e., did not reflect the brain's actual firing patterns) but

were fixed with respect to paired visual stimuli in conveying the location of the target. Thus, the animal used the visual information to learn the “meaning” of the electrical stimulation patterns and was later able to successfully reach to targets using cortical stimulation as feedback when the information conveyed by the visual stimuli was either degraded or completely removed. As part of this effort, the researchers also developed a computational model of multisensory integration in a neural network (Makin et al., 2013). The model demonstrates that correlations between visual and ICMS inputs are sufficient for the network to learn the ICMS signal. After learning, the model predicts how behavioral performance will change depending on the saliency of sensory inputs. The model's predictions were validated by the empirical results reported by Dadarlat et al., which demonstrated an increasing behavioral bias toward information conveyed by the somatosensory prosthesis as the information provided by the visual stimulus was degraded. Ongoing *REPAIR* efforts are investigating the use of computational models to derive optimal stimulation patterns and to determine whether sensory feedback can be provided to animals through the use of targeted optogenetic stimulation information (see Gilja et al., 2011 for discussion). For example, preliminary results suggest that artificial tactile sensation in the digit area can be induced through optogenetic stimulation of the non-human primate somatosensory cortex (May et al., 2013). These efforts offer unique approaches to providing sensory feedback within the context of closed-loop BCI.

While traditional closed-loop BCI systems provide feedback to the user, *REPAIR* researchers have incorporated the ability to provide feedback to both the user and the BCI system's neural decoder using adaptive models of brain function based on reinforcement learning. Some of these models have been interfaced directly with the brain, paving the way for enabling both the brain and the model to adapt to one another and to learn new behavioral tasks through closed-loop BCI performance (Marsh et al., 2013; Pohlmeier et al., 2014). Recent *REPAIR* efforts have developed the foundation for a fully autonomous, closed-loop BCI that uses real-time recorded neural activity from the non-human primate brain, both to directly control virtual reaching movements, and also to provide feedback that enables the system to automatically “learn” how to decode the brain's motor output signals (Marsh et al., 2013). In typical BCI systems, the neural decoder that controls virtual or robotic motor outputs must be trained on how to effectively translate signals from the brain's motor cortical regions into appropriate motor commands. However, *REPAIR* researchers discovered that neurons in the motor cortex also respond differentially depending on whether or not the virtual reaching movements accurately reflect the animal's intent. The researchers demonstrated that these biological “critic” signals can be used as feedback to the BCI in order to iteratively update the motor output decoder so that its output more accurately reflects the animal's intent. Such an approach is a radical departure from traditional BCIs that use kinematic signals for feedback. This new functionality has the potential to dramatically increase the flexibility of BCIs to quickly and automatically adapt to performance in dynamic environments, including performing tasks in changing environmental conditions, learning completely new tasks, and adapting to the brain's structural and functional changes that occur during injury and recovery.

2.3. Co-adaptive BCI for restoration of sensorimotor function

While the efforts described above are focused largely on invasive BCI technologies, an additional DARPA Small Business Innovation Research (SBIR) effort is supporting a collaborative effort between researchers at Advanced Brain Monitoring, Inc. and the University of Miami to develop a BCI system that utilizes non-invasively recorded EEG signals in patients with spinal cord injury to enable, and potentially even restore, movement of their paralyzed arms

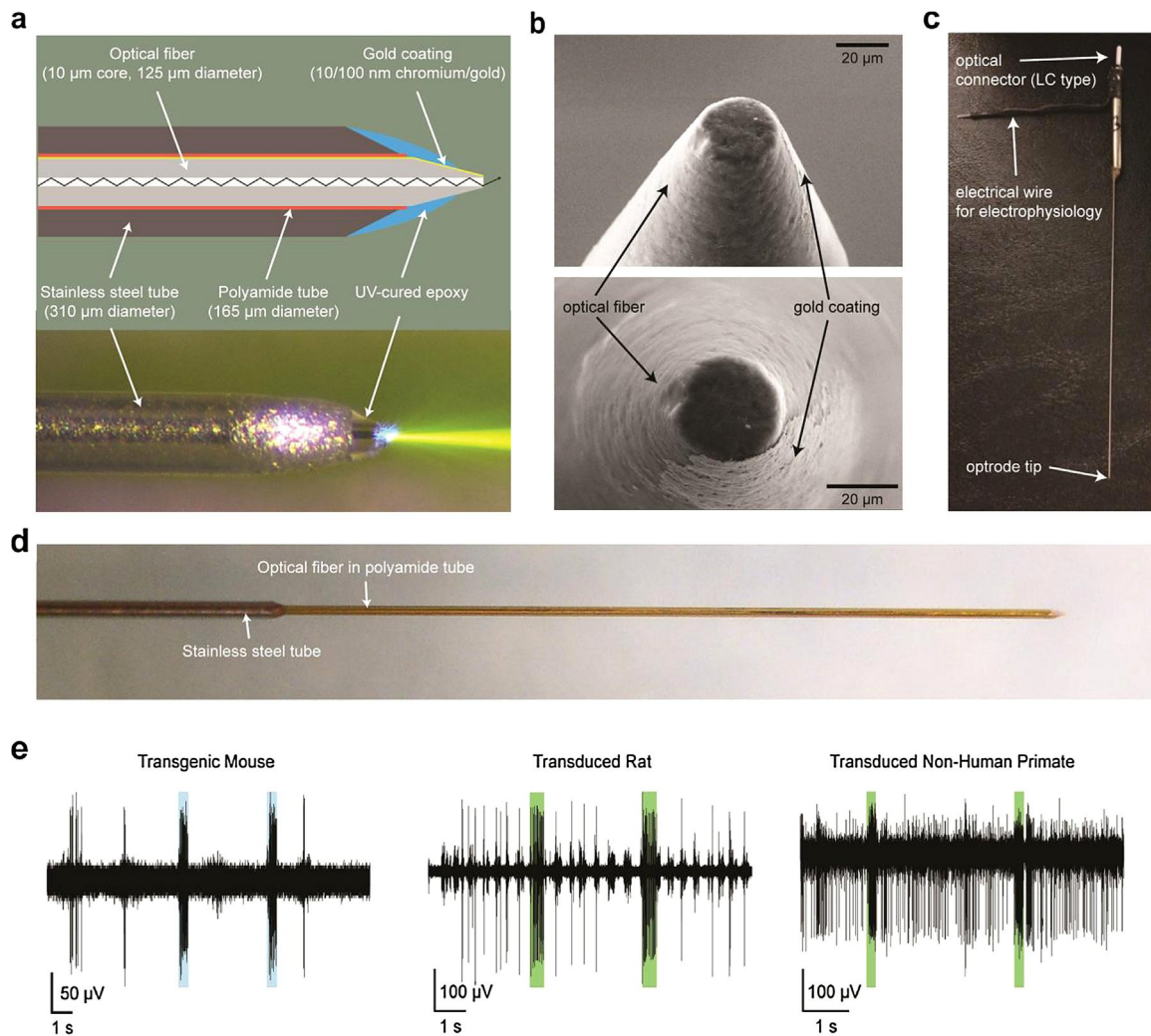


Fig. 2. Coaxial optrode for simultaneous electrical recording and optogenetic neuromodulation. (a) Coaxial optrode cross-sectional schematic (top) and photograph (bottom). (b) Scanning electron microscope images of coaxial optrode tip. (c) Full-length photograph of coaxial optrode. (d) Photograph of coaxial optrode depicting reinforcing thin stainless steel tube (310 μm diameter) and tissue penetrating portion of shaft (165 μm diameter). (e) Performance of the coaxial optrode is shown by optically modulated, in vivo electrophysiological recordings from somatosensory cortices in an anesthetized mouse (transgenic Thy1-ChR2/YFP, left), anesthetized rat (transduced with viral construct AAV5-CAMKII α -C1V1-eYFP, middle), and awake behaving non-human primate (transduced with AAV5-CAMKII α -C1V1-eYFP, right). Blue and green bars indicate timeframes of light delivery (at 473 nm for the mouse and 561 nm for the rat and non-human primate, respectively), highlighting light-induced increases in neuronal spiking activity. (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)

Adapted from "A coaxial optrode as a multifunction write-read probe for optogenetic studies in non-human primates," by I. Ozden, J. Wang, Y. Lu, T. May, J. Lee, W. Goo, D. J. O'Shea, P. Kalanithi, I. Diester, M. Dagnie, K. Deisseroth, K. V. Shenoy, and A. V. Nurmikko, 2013, *Journal of Neuroscience Methods*, 219(1), p. 144 & 148. Copyright 2014 by Elsevier. Adapted with permission.

(Rosset et al., 2013). To achieve this goal, the patient imagines opening or closing his or her hand while EEG signals are recorded. These EEG signals, particularly those generated in motor cortical areas associated with motor imagery, are detected, decoded, and used to trigger the activation of a functional electrical stimulation (FES) device worn on the patient's arm and hand. The FES device non-invasively delivers pulses of electrical stimulation to nerves innervating the muscles of the arm and hand. Depending on the locations of these pulses, the device can stimulate the patient's hand to either open or close. Importantly, if the patient perceives that the output of the FES device is not consistent with the patient's intent, the patient's brain generates "error potentials" in the ongoing EEG signal. Similar to the autonomous BCI concept investigated via invasive measures under the REPAIR program (described above), these non-invasively recorded error potentials are fed back to the closed-loop BCI system, enabling automatic adjustment of the algorithms that decode the brain's motor EEG signals. In this way, the system effectively "learns" the neural correlates underlying the

user's intentions to move, thus restoring behavioral function. It remains to be determined whether long-term use of this BCI system can also restore disrupted connectivity between the central and peripheral nervous systems, ultimately improving the ability of patients with spinal cord injury to make limb movements without reliance on the BCI.

2.4. Restorative Encoding Memory Integration Neural Device (REMIND)

While a majority of BCI efforts have focused on restoring sensory information (e.g., restoration of sight or hearing via retinal or cochlear implants) or motor behaviors (e.g., through peripheral or central nervous system control of computer cursor movements or prosthetic limbs), very few have attempted to develop a cognitive prosthesis. One such unique effort, initiated in 2002 under DARPA's Brain-Machine Interface (BMI) and Human Assisted Neural Devices (HAND) programs, and later supported by DARPA's REMIND

program (2009–2014), focused on the development of a BCI system for memory restoration. Under this program, collaborative efforts between teams led by researchers at Wake Forest University and University of Southern California demonstrated the ability to detect patterns of functional brain connectivity in the hippocampus and prefrontal cortex associated with successful memory encoding and retrieval, respectively. These naturally occurring spatiotemporal firing patterns across brain regions are emulated by a non-linear, multi-input, multi-output (“MIMO”) model, which inputs neural firing patterns from one brain region and outputs predicted firing patterns in a downstream brain area (Song et al., 2007, 2009). Moreover, in their investigation of neural correlates of behavioral performance on the memory task, the researchers discovered that the spatiotemporal patterns of hippocampal activity during memory encoding vary with respect to (1) whether the encoded item or event will subsequently be remembered or forgotten after a delay period, and (2) the nature of the item or event being encoded (in the rodent studies, encoded events are either a right or left lever press).

Taking their results a step (or rather, a leap) further, the researchers translated outputs of their computational model into electrical stimulation patterns that mimic the hippocampal firing patterns associated with correct encoding of a specific event. When applied to the hippocampus during memory encoding, the stimulation significantly improved, on a greater number of trials, the ability of rodents to subsequently remember an event (right vs. left lever press) following a long delay period (Berger et al., 2011; Hampson et al., 2012b). Importantly, when the investigators examined the effects of reversed stimulation (i.e., stimulating with a biomimetic pattern associated with successfully encoding a given lever press, but while the animal was actually pressing the opposite lever), they found that the animals' performance accuracy dropped below normal levels, further suggesting specificity of these stimulation patterns.

More recently, REMIND investigators demonstrated improvement of memory encoding and retrieval of items and their locations by non-human primates through stimulation of the hippocampus and prefrontal cortex, respectively (Hampson et al., 2012c, 2013). Achieving this challenge was largely enabled by newly developed techniques for conformal recording in the non-human primate brain described in this special issue (Opris et al., 2014; Fetterhoff et al., 2014). The biomorphic microelectrode arrays described by Opris et al. in this special issue have enabled conformal electrophysiological recordings as well as neurochemical measurements of glutamate concentration within cortical microcircuits, enabling the researchers to assess effects of electrical stimulation as well as molecular correlates of task performance in non-human primates (Opris et al., 2012, 2014).

Using the rodent model, REMIND researchers investigated the effect of hippocampal stimulation on restoration of memory performance in rodents following infusion of the glutamate receptor antagonist MK801 into the hippocampus (Berger et al., 2011). The MK801 infusion reversibly disrupted the signaling between two regions of the hippocampus that are crucial for memory encoding and drastically decreased behavioral performance on the memory task. However, when the animals received model-derived hippocampal stimulation, their performance on the memory task was in large part recovered. The researchers demonstrated similar restoration of performance by applying model-derived stimulation patterns to the prefrontal cortex of non-human primates following reversible pharmacological disruption of activity in this brain region (Hampson et al., 2012c).

During their initial studies, the REMIND investigators derived memory prosthetic stimulation patterns for a given animal based on a model of that animal's own brain activity. However, they later discovered that aspects of these spatiotemporal patterns of

brain activity exhibited remarkable consistency across animals (Deadwyler et al., 2013). To demonstrate the applicability of the model outputs across animals, the researchers trained one subset of rodents to be “experts” on the memory task – that is, these animals performed very well on the task, even when they had to remember the event for delays up to 60 s (which is quite difficult for a rat). Another subset of “delay-naïve” animals was trained on the task, but these animals were *not* trained to remember events across time delays of any length. When presented with trials containing a delay period between the initial lever press and the non-match response, the delay-naïve animals were not able to respond correctly. However, in a novel “donor-recipient” paradigm, in which an expert rat and a delay-naïve rat performed the memory task concurrently in separate chambers, hippocampal activity was recorded from the expert rat during memory encoding and translated in real-time to stimulation patterns that were immediately applied to the hippocampus of the delay-naïve rat. The performance of delay-naïve rats on long-delay trials was significantly improved, as compared to long-delay trials in which no stimulation was delivered. The researchers also leveraged the similarity of hippocampal firing patterns across over 40 rodents to develop a “generic” stimulation pattern, that, when applied to the hippocampus of a different animal during memory encoding, significantly boosted task performance (Hampson et al., 2012a). These studies, combined with the pharmacological disruption studies described above, raise the question of whether “generic” stimulation patterns may also be leveraged to recover memory performance in individuals with memory impairments resulting from neural injury or dysfunction.

Interestingly, Hampson et al. observed that applying model-derived stimulation patterns to the rodent hippocampus during memory encoding resulted in behavioral improvement of task performance not only on stimulated trials, but also to a lesser extent on intervening trials in which stimulation was not applied (Hampson et al., 2012a, 2012b). Moreover, performance on non-stimulated trials remained elevated for at least a week after stimulation was terminated. Such improvements in behavioral performance were also associated with increased prevalence of neural activity patterns that had been found to underlie the successful encoding of right or left lever presses on difficult trials (i.e., those with long delays). While neuronal mechanisms of stimulation-induced plasticity have not been directly investigated in the context of memory restoration, a new computational framework described in this special issue may provide the capability to model long-term changes in functional neuronal connectivity based on nonlinear, dynamic associations between spiking patterns of multiple neurons (Song et al., 2014). This computational modeling capability could provide key insights for future investigations of the effects of BCI usage on neural plasticity.

2.5. Reliable Neural Interface Technology (RE-NET)

With the remarkable success demonstrated under DARPA's BMI, HAND, and Revolutionizing Prosthetics programs, the formation of multi-disciplinary research teams such as BrainGate, and the advancement of BCI study at universities across the globe, researchers began to notice that the longevity of their BCI study capability varied dramatically. Initially, the vast majority of cortical implants were used in acute animal studies aimed at understanding and decoding brain activity. Some researchers transitioned from acute to chronic studies and were able to maintain partial cortical implant recording capability for years, while other researchers experienced interface failures much earlier.

The neural prosthesis research community began to form initial hypotheses as to the cause of these failures through histological analysis of explanted devices and surrounding tissue (Biran

et al., 2007; He and Bellamkonda, 2008). However, hypothesis testing proved challenging given the large number of variables to control, including surgical protocols, animal models, decoding approaches, and electrode technologies. Neural interfaces that are unreliable present a significant challenge to the clinical translation of these devices and can also delay progress in basic neuroscience research. Therefore, understanding the mechanisms of these failures became critically important. Today, overcoming interface failure is arguably the largest remaining hurdle that researchers striving to understand and decode brain function must achieve. Without overcoming these issues, the vision of life-long BCI systems will remain just outside of reach.

The *Reliable Neural Interface Technology (RE-NET)* program was established to identify and solve problems of extracting neural information from the nervous system at the scale and rate necessary to control high-performance prosthetic-limbs for chronic periods of time (Judy, 2012). This DARPA effort contained three separate components designed to identify and eliminate interface failure. The first effort, *Histology for Interface Stability over Time (HIST)*, initiated in 2010, was developed to characterize and quantify neural signal detection failure associated with chronically implanted electrode arrays. The *Reliable Central nervous system Interfaces (RCI)* and *Reliable Peripheral Interfaces (RPI)* programs, both of which began in 2011, were aimed at preventing interface failures, advancing motor decoding performance of neural interface technologies placed in the brain, peripheral nerves, and muscles, and restoring somatosensory function.

The ability to detect neural activity is dependent on the quality of the device. The *HIST* program evaluated both biotic and abiotic device failure modes, that is, the biological or tissue responses that may be related to the disrupted or reduced ability to detect neural activity (Karumbaiah et al., 2013; Saxena et al., 2013), as well as the device-related or system-related failures such as material, manufacturing, or system interconnects (Prasad and Sanchez, 2012; Prasad et al., 2014).

RCI efforts developed and demonstrated novel materials, electrodes, and interface systems to increase the reliability and functional duration of cortical interface systems (Tien et al., 2013). Additional efforts under this program have focused on emulating and subsequently decoding motor control signals from functional brain networks in order to control advanced prosthetic devices. One such effort, presented in this special issue, involved the development of a novel virtual reality system for non-human primates capable of emulating all the natural movements of a healthy limb (Putrino et al., 2014). This RCI outcome will enable researchers to demonstrate reliable high-bandwidth control of unconstrained, many-degree-of-freedom movements.

Restoration of function has long-been the leading goal of researchers developing novel medical devices. The RPI effort improved peripheral nervous system recording capability through the use of penetrating and non-penetrating electrodes placed in spinal and peripheral nerves. Additional developments by the RPI program included novel peripheral interface devices, advanced targeted muscle re-innervation techniques (Abidian et al., 2012; Baghmanli et al., 2013), new algorithms for on-line decoding of motor control signals, and new methods for naturalistic sensory percept generation through modulation of peripheral nerve electrical stimulation parameters. In this special issue, *RE-NET RPI* researchers describe the development of a peripheral interface system to record and stimulate at various locations across multiple nerves (Thota et al., 2014). In addition, one service member at Walter Reed National Military Medical Center has become the first amputee to receive implantable technology in effort to improve control of his prosthetic device. This work is planned for expansion and holds great promise for the future of prosthetic interface technology and the restoration of upper-limb function in amputees, as

described by Pasquina et al. in this special issue (Pasquina et al., 2014).

RE-NET efforts are projected to continue through 2015 and will build on the momentum of the program with a heavy emphasis on demonstration of life-long neural interface systems. The renewed focus on the peripheral nervous system has produced a level of prosthetic control above projected capability. Peripheral nerves and muscles are ideal targets for amputees since peripheral nerve surgeries are routinely performed in this population; therefore, inclusion of nerve implants poses little added risk. Novel approaches to record and stimulate sensory nerves are needed to restore touch and proprioception. *RE-NET* will continue to capitalize on this momentum by developing advanced peripheral interface devices with chronic, stable signal capture and decoding capabilities. Moreover, these systems will provide amputees with prosthetic sensory feedback to further improve sensorimotor control. Ultimately, these advances are intended to increase the extent of embodiment of neurally controlled prosthetic devices so that such devices will be widely accepted and utilized regularly by clinical populations. Achieving this vision is the main thrust of DARPA's new Hand, Proprioception, & Touch Interfaces (HAPTIX) program which is projected to begin in late 2014 and run until 2020.

3. DARPA BCI efforts to improve human training and performance

While the DARPA-funded efforts featured above are focused on development of BCI interfaces ultimately aimed at restoring neural and behavioral function, DARPA has also made notable investments in the development of BCI systems intended to improve training and performance of healthy individuals. The *Accelerated Learning* program has developed novel training paradigms, including those leveraging BCI, to accelerate improvements in human performance. The *Narrative Networks (N2)* program is developing new techniques to quantify the effect of narratives on human cognition and behavior, including initial development of a closed-loop BCI system that adapts a narrative in response to a listener's EEG signals. Such a system would have numerous applications to training and human performance domains. The *Neurotechnology for Intelligence Analysts (NIA)* and *Cognitive Technology Threat Warning System (CT2WS)* programs both have utilized non-invasively recorded "target detection" brain signals to improve the efficiency of imagery analysis and real-time threat detection, respectively. The *Low-cost EEG Technologies* effort aims to develop more affordable EEG recording systems, thus expanding the reach of BCI development opportunities to a broader community of both professional and amateur neuroscientists. These DARPA programs have funded scientific advances that range from fundamental new discoveries about the functions of the human brain to the development of new human-in-the-loop systems that leverage non-invasively recorded neural responses to optimize human performance.

3.1. Accelerated Learning

The *Accelerated Learning* program (2007–2012) sought to revolutionize learning in the military environment through the development of reliable and quantitative methods for measuring, tracking, and accelerating skills acquisition. The program primarily focused on detecting non-invasively measured neural and other physiological correlates of task learning, with an end goal of producing a two-fold increase in an individual's learning rate. In Phase I of the program, researchers conducted fundamental research to identify neural correlates of task learning and to develop a proof of principle that these findings could be leveraged to accelerate learning. The methods used included neurophysiologically driven

training regimes, neurally optimized stimuli, and development of feedback interventions delivered through a closed-loop BCI. Phase II focused on demonstrating a two-fold increase in the rate of learning in a military population on an operationally relevant task. Complementary components that further aided in attaining the goals of the program included development of neurally based techniques for maintenance of acquired skills, prediction of skill acquisition based on real-time neural activity, and the ability to present neural state status in the form of sensory feedback to accelerate an individual's learning progression and thus improve human performance.

Efforts under *Accelerated Learning* demonstrated that it was possible to leverage brain imaging, EEG, and other neurophysiological measures to quantitatively characterize physiological states reflective of novice, intermediate, and expert levels of performance. Researchers also succeeded in identifying specific brain regions, activity patterns, and networks associated with the acquisition of complex tasks, utilizing these findings to accelerate learning of those tasks by a factor of two. Relevant to this review, Advanced Brain Monitoring, Inc. developed a suite of adaptive and interactive neuro-educational technologies (Interactive Neuro-Educational Technology, or I-NET[®]) to accelerate skill learning and incorporated these tools into a closed-loop system known as the Adaptive Peak Performance Trainer (APPT[®]) (Raphael et al., 2009). This system includes four main components: integration of real-time EEG into closed-loop tutorials, identification of psychophysiological characteristics of expertise using Advanced Brain Monitoring's wireless EEG acquisition system (Berka et al., 2004), development of sensor-based feedback to deliver real-time physiological state feedback, and identification of neurocognitive factors that are predictive of skill acquisition to enable early interventions. Rifle marksmanship training was used as the militarily relevant task, as it is a core military skill that involves both classroom learning and field practice requiring sensory, motor, and cognitive skills. The APPT[®] system incorporates knowledge of EEG, electrocardiography (ECG), respiration rate, and eye tracking signatures of learning stages. The system can provide continuous physiological monitoring and feedback (visual, auditory, or haptic) to the trainee in real-time through integration of algorithms that derive physiological state changes based on sensor inputs. A preliminary study suggests that use of the I-NET/APPT increased the learning trajectory of novice participants by a factor of 2.3, compared to novice participants who trained with an identical protocol without the APPT[®] (Behneman et al., 2012). Importantly, the system provides a closed-loop BCI platform for assessing combinations of pre-training interventions designed to accelerate psychophysiological control and combat-relevant skills acquisition.

3.2. Narrative Networks (N2)

Initiated in 2011 and anticipated to continue through 2015, the N2 program was created to develop a quantitative approach to the analysis of narratives and their influence on human cognition and behavior. Narratives exert a powerful influence on human thoughts, emotions, memories, and behavior, and can be particularly important in security contexts (Casebeer and Russell, 2005). Through an improved basic understanding of narrative effects, tools are being developed to detect brain activity associated with narrative influence and to emulate this activity in the context of larger environmental factors with models of narrative influence on individual and group behavior. These tools will facilitate faster and better communication of information in foreign information operations. To this end, one goal of the program is to create BCI technologies that close the loop between the storyteller and consumer, allowing neural responses to a narrative stimulus to dictate the story's trajectory. In this way, moment-by-moment neural activity

would drive the subsequent story outcome, resulting in an individualized narrative tailored by neural signatures associated with cognitive processes such as attention and empathy.

Since the brain is the proximate cause of behavior, N2 has focused much of its early research on understanding how stories impact the brain. Using non-invasive brain imaging techniques such as EEG and functional magnetic resonance imaging (fMRI), researchers have detected various brain responses to particular story elements and correlated these responses with emotional, attitudinal, and behavioral effects in the story consumer. When an individual listens to a compelling story, particular patterns of EEG activity have been shown across individuals to correlate with levels of sensory engagement, empathy, and narrative cohesion in the listener. Similarly, while watching suspenseful video clips, individuals display characteristic fMRI patterns that correlate with moments of high narrative transportation, when the listener feels more transported into the narrative world. These decoded patterns of neural activity are correlated with behavioral changes induced by the narrative. For example, investigators have predicted with high accuracy whether or not an individual will donate to a given charity after watching a related narrative, based on their neural responses during the video.

In conflict resolution and counterterrorism scenarios, detecting the neural response underlying empathy induced by stories is of critical importance. N2 researchers have explored how narratives can reinforce in-group and out-group memberships and induce profound empathy gaps between members of these groups. In exploration of the neural code representing physical pain and emotional suffering, investigators used a series of 96 text-based stories, which varied in the levels of physical pain and emotional suffering experienced by the protagonist. While subjective ratings of pain and suffering were highly correlated across the various stories, the neural responses to these measures were distinct, even within the pain network of the brain (Bruneau et al., 2013). Therefore, measures of neural activity may give us a more precise window into the feelings and emotions induced by narrative consumption.

Having detected a number of neural states associated with narrative influence, investigators are using this information to develop novel brain-in-the-loop systems to improve narrative creation and delivery. Efforts by Advanced Brain Monitoring initiated under N2 include the development of a closed-loop BCI system that integrates the human audience member into the storytelling process by recording the story recipient's EEG during presentation of a narrative video. Brain activity recordings are outputted to the system, and based on algorithms designed to detect the neural states previously mentioned, the story is intended to branch into alternative scenarios when certain states reach threshold. For example, if engagement levels drop below an optimal level, the narrative would take an alternate branch designed to increase aspects of story engagement. In this way, this narrative testbed could be used to create optimal narratives tailored to a specific individual or group of people. Notably, Advanced Brain Monitoring's system is designed to synchronize multiple users' neural inputs into the closed-loop system (Stevens et al., 2012), allowing for the potential to enable group-level activity to influence the narrative outcomes. Clear applications for this BCI technology exist not only for N2-related goals but also in the education and entertainment industries.

3.3. Neurotechnology for Intelligence Analysts (NIA)

The goal of the NIA program (2005–2014) was to develop new BCI systems utilizing non-invasively recorded brain signals to significantly increase the efficiency and throughput of imagery analysis. In recent years, operational technologies have been developed that have exponentially increased collection and storage capabilities of intelligence data, including overhead imagery

collected via satellites and remotely piloted aircraft. The increase in the availability of enormous imagery datasets has led to the challenge of effectively searching through and analyzing the imagery in a timely manner with limited analytical resources. The current operational procedure for broad area search for targets in overhead imagery is an extremely time- and labor-intensive brute force method, and current computer vision approaches to imagery analysis are nowhere close to matching the target detection capabilities of the human visual system.

The neuroscientific basis of the BCI systems developed under NIA is that, upon seeing a target of interest, a unique set of neural responses, including an event-related potential known as a “P300,” is elicited in a person’s non-invasively recorded EEG. This P300 response is typically observed approximately 300 ms following presentation of a target image and appears as a positive-going deflection in the EEG signal, compared to the signal elicited by non-target images. Neural signatures of target detection have been observed in response to targets in images presented sequentially at rapid rates of up to 20 images per second (Sajda et al., 2003). At such fast presentation rates it is not feasible to match target images with behavioral responses such as button presses, which are generally slower than 300 ms and quite variable in response time.

The NIA systems encompassed a “human-in-the-loop” approach that leveraged the use of new decoding algorithms to detect neural signatures of target detection on a single-trial basis (see Fig. 3). Satellite images were divided into small segments and then presented to imagery analysts at rates between 0.5 and 10 images per second while the analysts’ brain responses were measured with EEG (Qian et al., 2009; Sajda et al., 2010; Macdonald et al., 2011). The NIA systems’ decoding classifiers were designed to automatically detect spatiotemporal features within the EEG signal associated with viewing targets as compared to non-target images. Additionally, the NIA target detection classifiers integrated computer vision, eye-tracking data, and/or EEG correlates of attention. Based on output from the systems’ classification algorithms, image segments were either given a prioritization score based on their calculated probability of containing a target, or marked as potential target images based on the classifier’s threshold levels of brain responses. Satellite imagery locations most likely to contain targets were then presented back to the user for final verification and assessment. Importantly, given that target detection brain responses are largely independent of target type or modality, the BCI systems developed under the NIA program are able to immediately adapt to changes in operational requirements, such as searching for new and/or multiple classes of targets in different imagery modalities. Thus, the NIA approach eliminates the need for cumbersome system parameter adjustments required for detection of new types of targets by systems relying solely on computer vision approaches. In a series of formal evaluations conducted on three of the NIA systems with over 40 professional imagery analysts in 2008–2009, use of the NIA systems resulted in up to a 10-fold increase in analysis throughput (area of imagery analyzed per unit time) with no loss of target detection sensitivity, as compared to the analysts’ performance using their standard imagery analysis approaches.

3.4. Cognitive Technology Threat Warning System (CT2WS)

Like the NIA program, CT2WS, initiated in 2007, funded the development of a non-invasive BCI system that detects the human user’s “target detection” brain responses including the P300, as measured by EEG (Khosla et al., 2011; Weiden et al., 2012). Rather than detecting targets in overhead imagery, however, the goal of CT2WS is to detect potential threats during real-time surveillance operations. For the purposes of demonstration, the program focused on surveillance from a forward operating base, for which threats included vehicles (mounted forces) and individuals on foot

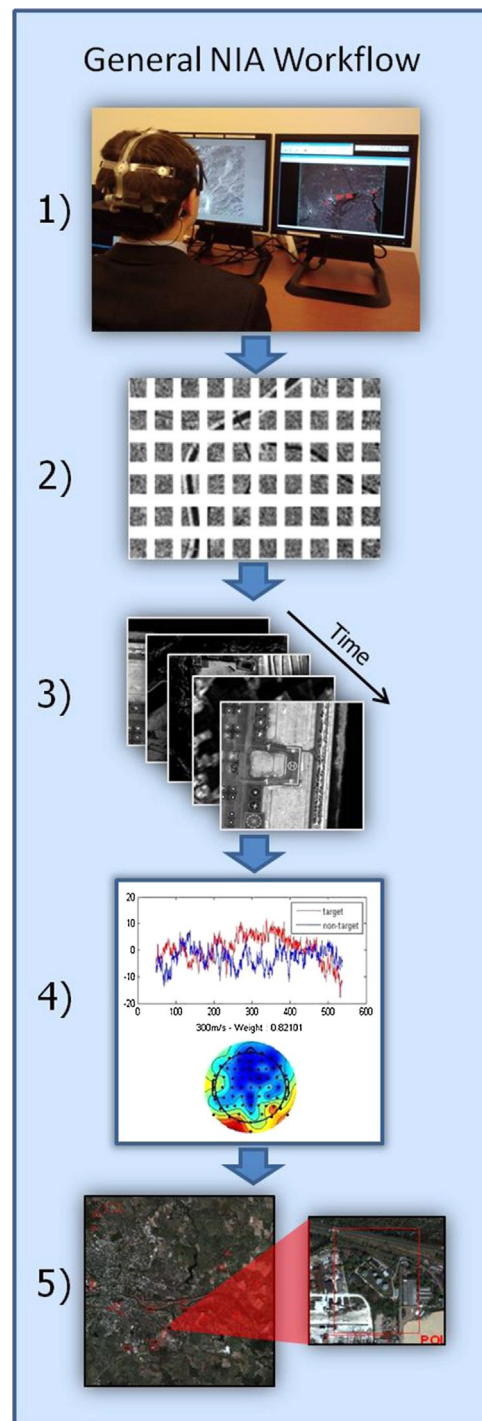


Fig. 3. General workflow procedures implemented by the Neurotechnology for Intelligence Analysts BCI systems to detect targets of interest in satellite imagery. (1) The analyst user is fitted with an EEG cap containing electrodes that non-invasively record the analyst’s neural signals. (Photo courtesy of Neuromatters, LLC). (2) Overhead imagery is divided into segments or “chips,” which are then (3) presented to the user in rapid succession (0.5–10 images per second). (4) Each image chip containing one or more targets of interest elicits a distinctive neural response in the analyst, which is measured by the electrodes in the analyst’s EEG cap. (5) The NIA system decodes the analyst’s neural signals and automatically prioritizes locations within the image that are most likely to contain targets. Using standard imagery analysis software, these image locations are presented to the analyst for review, validation, and further annotation.

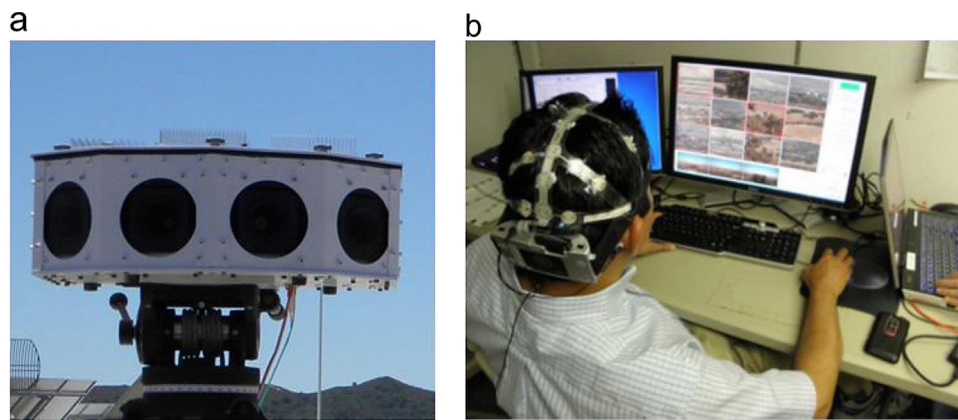


Fig. 4. Equipment used to demonstrate threat detection performance of the CT2WS BCI system at Camp Roberts, CA in 2012. (a) A four-camera system recorded real-time surveillance video with 120-degree field-of-view and 120-megapixel resolution. (b) EEG cap (Advanced Brain Monitoring B-Alert X24, 20 EEG channels) used to non-invasively record operators' neural activity while viewing rapidly presented visual stimuli.

(dismounted forces). The system, developed by a research team at HRL Laboratories, LLC, utilizes advanced flat-field, wide-angle optics and high pixel-count digital imagers to record real-time surveillance video (Huber et al., 2013). Neuromorphic computer vision algorithms designed to emulate the brain's visual system are used to detect potential threats within the video (Khosla et al., 2013). The system then presents still frames containing these potential threats in rapid succession to the user (a method referred to as Rapid Serial Visual Presentation or RSVP). The user's neural signals enable further classification of potential threats; when a threat is detected, a visual cue is provided to the user, alerting the user to focus on that image.

During a weeklong evaluation at Camp Roberts, CA in 2012, the threat detection performance of the CT2WS system (four cameras with a 120-degree field-of-view, see Fig. 4) was compared side by side to the performance of the Cerberus Scout, a state-of-the-art commercial surveillance system used in theater by Army and Marine Corps units. The CT2WS system demonstrated a probability of threat detection almost twice that of the Scout (91% and 53%, respectively), and an extremely low rate of five false alarms per hour out of more than 2300 events per hour (not measured for Scout, but substantially higher). Also in 2012, a pilot study with five subjects indicated that using the CT2WS system reduced the operator workload (measured by the mean for the NASA-TLX categories of mental demand, physical demand, temporal demand, performance, effort, and frustration) by a factor of two compared to the unaided eye.

The CT2WS program is also funding the development of dry-electrode EEG headsets that would improve the usability of fieldable BCI systems for applications such as threat detection (described above). Traditional EEG headsets rely on conductive paste, gel, or saline solution to non-invasively record the brain's electrical signals. As a consequence, these devices are often cumbersome to apply and unappealing to the user, given the wetness or residue that remains on the user's scalp and hair following removal of the headset. Off-the-shelf, dry-electrode headsets have been previously developed, primarily for the gaming industry; however, the signal-to-noise ratio of these systems is too low to reliably detect many EEG components of interest for neuroscience efforts aimed at improving human training and performance, particularly when single trial analysis is required. Additionally, currently available dry electrode headsets are often more susceptible to interference such as motion artifacts, compared to systems utilizing paste, gel, or saline. The CT2WS program developed three novel dry-electrode EEG headsets (see Fig. 5), all wireless, with sensor channels ranging in number from 20 to 32, and weight ranging from 40 to 635 g (Chi et al., 2012, 2013; Davis et al., 2013; Halford et al., 2013). Empirical tests of the dry-electrode headsets and a wet-electrode baseline system compared P300 response performance on image stimuli, "oddball" image stimuli, video stimuli, steady state visually evoked potential, auditory evoked potential, and artifacts including eyes open, eyes closed, blinks, and jaw clench. All three systems correlated reasonably well to the baseline. Further research and development is needed to optimize system robustness to motion artifacts.



Fig. 5. Three dry-electrode EEG caps designed and tested under the CT2WS program. (Left) B-Alert X24 Wireless EEG Headset System designed by Advanced Brain Monitoring, Inc. (ABM), with 24 standard wet sensors replaced with semi-dry, hydrogel-based sensors. (Middle) Dry-electrode EEG system developed by Quantum Applied Science and Research, Inc. (QUASAR), containing 20 hybrid resistive-capacitive dry-electrode sensors. (Right) EEG system developed by researchers at the University of California at San Diego (UCSD), containing 32 dry-electrode sensors in a soft, adjustable headset.

3.5. Low-cost EEG Technologies

The CT2WS effort demonstrated that dry-electrode headsets enable collection of EEG data with high signal-to-noise ratios, suitable for research grade data collection. However, these cutting-edge systems are typically too expensive and difficult for non-neuroscientists to use. In the last few years, commercial companies have developed lower-cost EEG headsets, but these systems often have poor signal-to-noise ratios or encrypt the data stream, requiring substantial investment to gain full data access. In 2013, a DARPA SBIR program was launched to address this EEG cost, data quality, and usability gap. The goal of this SBIR effort is to facilitate brain-in-the-loop research by developing a low-cost (\$30, price of parts), research grade EEG system and accompanying software to enable usage by non-neuroscientists. Such a system would allow for large-scale crowdsourced neuroimaging research, not currently feasible. The neuroscientist community has leveraged crowdsourcing for large volume imagery data analysis with projects such as EyeWire and KNOSSOS (Marx, 2013). Likewise, the psychologist community has leveraged crowdsourcing for large volume survey and behavioral data collection with tools like Amazon's Mechanical Turk and Qualtrics. A \$30 EEG system would enable similar crowdsourcing data collection efforts for neuroimaging as well.

Development to date has focused on a number of different approaches. With regard to the sensors, teams have explored 3-D printing of dry electrodes directly to the headgear. For electronics development, others have adopted a completely open source approach to the design, iterating with the citizen scientist community for improved electronics' designs. Still others have created augmented reality software and apps to aid in the donning and use of the EEG devices.

This SBIR effort is anticipated to continue through 2015 and aims to develop a truly enabling technology. With respect to the President's BRAIN initiative, novel BCI technologies are needed that not only extend what information can be extracted from the brain, but also who is able to conduct and participate in those studies. Applications exist not only in the crowdsourced neuroscience domain, but also in education, entertainment, and a myriad of possible BCI-related projects.

4. Future efforts and challenges for brain-computer interface technologies

Given the latest advances in brain-computer interfaces, a number of challenges remain in optimizing the capabilities, robustness, and usability of such systems, including the development of BCI devices for human use. One needed capability advancement is the development of enhanced recording techniques that enable real-time measurements of neural activity and structure across a wide range of spatial scales (from one to millions of neurons) and temporal scales (from milliseconds to years). A new DARPA program entitled *Neuro Function, Activity, Structure, and Technology* (Neuro-FAST) aims to develop novel optical methods to enable real-time functional recording of thousands of neurons, with single-neuron resolution, in awake, behaving animals. Likewise, to effectively implement BCI systems for clinical use by individuals with less severe clinical cases or who are unwilling to undergo the risks of neurosurgery, or for enabling efficient performance by healthy users, there exists a need for the development of subcutaneous and fully non-invasive neural interfaces that are both portable and capable of recording activity from cortical and deep brain structures at high spatial and temporal resolution.

As new technologies enable progressively more neural, physiological, and behavioral data to be collected, the need for improved computational processing and mathematical dimensionality

reduction techniques will increase exponentially in order to facilitate effective analysis and use of the data. These needs are especially essential for closed-loop BCI systems that rely on automated, real-time analysis of recorded neural signals. Effective analysis and integration of data across research groups will also require revolutionary new approaches to data sharing, including standardization of protocols and data formats, ability to effectively merge data across multiple modalities and scales, and incentive structures that promote sharing of data and collaborative efforts across individual laboratories. Notably, for new efforts under DARPA's brain function research portfolio, high priority is being placed on the sharing of newly developed protocols and resulting data. While DARPA has long placed an emphasis on collaboration across multi-disciplinary research teams, selection criteria for new efforts also include requirements for sharing data among DARPA-funded teams, as well as making data available to the broader scientific research community at an accelerated pace.

With respect to the ultimate goal of transitioning BCI systems for chronic use by humans, the need for robust interface hardware and computational models – beyond the advances made by the DARPA-funded programs described above – is becoming increasingly important. Implanted neural interface hardware must remain functional and biologically compatible over years and even decades to reduce the need for multiple surgical procedures. Additionally, these systems should enable the application of new software updates without requiring surgical removal of implanted hardware. While surgical risks are not applicable to non-invasive BCI hardware, non-invasive systems are associated with a distinct set of challenges, including the need to minimize system set-up time, as well as the need for robustness in changing environmental conditions and against variation in sensor placement across multiple uses. Computational model components of BCI systems should be compatible with neural plasticity over chronic use and should function across various contexts and associated brain states, without the requirement for extensive and/or frequent calibration procedures. The systems must also remain robust in the midst of external interference, such as electrical interference (e.g., while using a mobile phone), and must include sufficient safeguards to prevent deliberate interference by unauthorized individuals.

While a majority of state-of-the-art, closed-loop BCI systems translate recorded neural signals into functions performed by a machine – for instance, the movement of a computer cursor or robotic limb – recent BCI efforts have begun to utilize recorded neural activity to generate feedback signals that are delivered directly to the user through stimulation of muscles, nerves, or the brain itself. Advances in both invasive and non-invasive neural interfaces, as well as computational models, are needed to enable precisely targeted stimulation with high spatial and temporal resolution to the brain or periphery of humans to enable (1) substitution for lost sensory inputs (e.g., prosthetic sensation of touch for amputees), (2) immediate correction of dysfunctional networks (e.g., abnormal neural firing detection and mitigation), and (3) long-term restoration of healthy functional networks through leveraging of the brain's natural plasticity mechanisms.

Two new programs under DARPA's brain function research portfolio were established in 2014 to quantitatively characterize the complex neuronal networks underlying both healthy and aberrant cognitive and behavioral function, and to develop devices that deliver advanced therapeutic neural stimulation to human clinical populations. The *Systems-Based Neurotechnology for Emerging Therapies* (SUBNETS) program aims to address the problem that state-of-the-art methodologies for treating complex neuropsychiatric and neurologic disorders involve imprecise surgical, pharmacological, psychotherapy, or deep brain stimulation (DBS) approaches that are implemented through a slow, trial-and-error based process. This is a particular challenge for the U.S. military,

as in recent years, veterans receiving mental health care from the Department of Veterans Affairs (VA) have constituted almost a third of the total number of veterans receiving health care from the VA (U.S. Government Accountability Office, 2011). The SUBNETS program will attempt to develop novel neural interfaces and therapeutic approaches for human patients with intractable illnesses by developing fully implantable medical devices for multi-site, systems-based neural recordings, deriving new computational models to characterize the distributed neural interactions that underlie a variety of neuropsychiatric and neurological conditions, and delivering safe, targeted therapeutic neural stimulation through closed-loop BCI.

The vision of DARPA's *Restoring Active Memory (RAM)* program is to develop computational models that quantitatively characterize the biological underpinnings of the complex organization of memories in the human brain, and to integrate these models into a therapeutic device for targeted memory restoration in human patients with intractable illnesses who are suffering from memory deficits. This clinical population is highly relevant to the U.S. military, given that traumatic brain injury frequently results in deficits in retrieving memories formed prior to the injury and/or forming and retaining memories of new experiences following injury onset. The RAM program focuses on restoring declarative memories – the memories of facts and events that can be explicitly recalled. To achieve the goal of declarative memory restoration, the RAM program aims to fund the development of new neural interface hardware that can target multi-scale neural underpinnings of declarative memory in human patients with high spatial and temporal resolution. It is anticipated that the data collected via these neural interfaces will be leveraged to develop and validate mathematical algorithms that characterize the neural correlates of successfully (and unsuccessfully) encoding and/or retrieving specific types or attributes of memory. The computational models developed under RAM are envisioned to be integrated into a closed-loop BCI system that can restore specific types or attributes of memory through the use of targeted neural stimulation.

As both SUBNETS and RAM involve the application of new technologies to human clinical populations, DARPA has been working closely with the FDA. These collaborations between DARPA and the FDA have led to new innovation pathways for device development (U.S. Food and Drug Administration, 2011a, 2011b). Continued interaction among government agencies, clinical investigators, and technologists are expected to facilitate the establishment of a variety of new indications, outcome metrics, and endpoints for neuroprosthetic devices.

DARPA is committed to ensuring that the efforts it funds follow all laws and regulations designed to protect humans and animals involved in scientific research. In addition, DARPA has established a panel of individuals with expertise in ethical, legal, and societal implications (ELSI) of neuroscientific research to reflect on and inform DARPA efforts in this domain, and to facilitate communication between DARPA and relevant stakeholder communities including the neuroscience and bioethics communities. ELSI panelists consider the potential downstream implications of agency-funded neuroscientific developments, including those relating to safety, privacy, foreign policy and security (see, e.g., Casebeer, 2013, for a framework discussion), recognizing that some such implications may unfold over years or even decades following DARPA's initial investments. More broadly, the agency is committed to fostering public awareness and understanding of the potential applications of its efforts to advance neuroscience technologies and the field of BCI.

The future of brain–computer interfaces depends upon multi-disciplinary collaborations among neuroscientists, psychologists, clinicians, engineers, and mathematicians, and upon ongoing communication with relevant stakeholder communities including

regulators, physicians, and patients. Effectively bringing together these diverse fields and communities will facilitate the development of new tools to measure, quantify and model dynamic, multi-scale brain activity and will ultimately lead to novel therapeutic regimens and training paradigms capable of restoring and improving neural, cognitive, and behavioral function.

Disclaimer

The opinions expressed herein belong solely to the authors. They do not represent and should not be interpreted as being those of or endorsed by the Defense Advanced Research Projects Agency, the Department of Defense, or any other branch of the federal government. The durations listed for the DARPA programs mentioned are estimates only; programs may be adjusted at any time due to shifting agency priorities and the availability of funds.

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References

- Abidian MR, Daneshvar ED, Egeland BM, Kipke DR, Cederna PS, Urbanek MG. Hybrid conducting polymer-hydrogel conduits for axonal growth and neural tissue engineering. *Adv Healthc Mater* 2012;1(6):762–7, <http://dx.doi.org/10.1002/adhm.201200182>.
- Ames KC, Ryu SI, Shenoy KV. Neural dynamics of reaching following incorrect or absent motor preparation. *Neuron* 2014;81(2):438–51, <http://dx.doi.org/10.1016/j.neuron.2013.11.003>.
- Andersen RA, Schieber MH, Thakor N, Loeb GE. Natural and accelerated recovery from brain damage: experimental and theoretical approaches. *IEEE Pulse* 2012;3(2):61–5, <http://dx.doi.org/10.1109/MPUL.2011.2181093>.
- Armiger RS, Tenore FV, Bishop WE, Beaty JD, Bridges MM, Burck JM, et al. A real-time virtual integration environment for neuroprosthetics and rehabilitation. *Johns Hopkins APL Tech Dig* 2011;30(3):198–206.
- Baghmanli Z, Sugg KB, Wei B, Shim BS, Martin DC, Cederna PS, et al. Biological and electrophysiologic effects of poly(3,4-ethylenedioxythiophene) on regenerating peripheral nerve fibers. *Plast Reconstr Surg* 2013;132(2):374–85, <http://dx.doi.org/10.1097/PRS.0b013e3182959f63>.
- Becker DB. Patent No. US2285885 A. United States; 1942.
- Behneman A, Berka C, Stevens R, Vila B, Tan V, Gallowsay T, et al. Neurotechnology to accelerate learning: during marksmanship training. *IEEE Pulse* 2012;3(1):60–3, <http://dx.doi.org/10.1109/MPUL.2011.2175641>.
- Berg JA, Dammann JF, Tenore FV, Tabot GA, Boback JL, Manfredi LR, et al. Behavioral demonstration of a somatosensory neuroprosthesis. *IEEE Trans Neural Syst Rehabil Eng* 2013;21(3):500–7, <http://dx.doi.org/10.1109/TNSRE.2013.2244616>.
- Berger TW, Hampson RE, Song D, Goonawardena A, Marmarelis VZ, Deadwyler SA. A cortical neural prosthesis for restoring. *J Neural Eng* 2011;8(4):046017, <http://dx.doi.org/10.1088/1741-2560/8/4/046017>.
- Berka C, Levendowski DJ, Cvetinovic M, Petrovic MM, Davis GF, Lumicao MN, et al. Real-time analysis of EEG indices of alertness, cognition and memory acquired with a wireless EEG headset. *Int J Human-Comput Interact* 2004;17(2):151–70.
- Biran R, Martin DC, Tresco PA. The brain tissue response to implanted silicon micro-electrode arrays is increased when the device is tethered to the skull. *J Biomed Mater Res A* 2007;82(1):169–78.
- Birbaumer N, Murguialday AR, Weber C, Montoya P. Neurofeedback and brain–computer interface: clinical applications. *Int Rev Neurobiol* 2009;86:107–17, [http://dx.doi.org/10.1016/S0074-7742\(09\)86008-X](http://dx.doi.org/10.1016/S0074-7742(09)86008-X).
- Borton DA, Yin M, Aceros J, Nurmikko A. An implantable wireless neural interface for recording cortical circuit dynamics in moving primates. *J Neural Eng* 2013;10(2):026010, <http://dx.doi.org/10.1088/1741-2560/10/2/026010>.
- Bruneau E, Dufour N, Saxe R. How we know it hurts: item analysis of written narratives reveals distinct neural responses to others' physical pain and emotional suffering. *PLOS ONE* 2013;8(4):e63085, <http://dx.doi.org/10.1371/journal.pone.0063085>.
- Carmena JM, Lebedev MA, Crist RE, O'Doherty JE, Santucci DM, Dimitrov DF, et al. Learning to control a brain–machine interface for reaching and grasping by primates. *PLoS Biol* 2003;1(2):E42.
- Casebeer WD. Ethics and the biologized battlefield: moral issues in 21st-century conflict. In: Armstrong RE, Drapeau MD, Loeb CA, Valdes JJ, editors. *Bio-inspired innovation and national security*. Washington, DC: National Defense University Press; 2013. p. 293–303.

- Casebeer WD, Russell JA. *Storytelling and terrorism: towards a comprehensive "counter-narrative strategy"*. *Strateg Insights* 2005;4(3):1–16.
- Chen KH, Dammann JF, Boback JL, Tenore FV, Otto KJ, Gaunt RA, et al. The effect of chronic intracortical microstimulation on the electrode-tissue interface. *J Neural Eng* 2014;11(2):026004. <http://dx.doi.org/10.1088/1741-2560/11/2/026004>.
- Chhatbar PY, Francis JT. Towards a naturalistic brain-machine interface: hybrid torque and position control allows generalization to novel dynamics. *PLOS ONE* 2013;8(1):e52286. <http://dx.doi.org/10.1371/journal.pone.0052286>.
- Chi YM, Wang YT, Wang Y, Maier C, Jung TP, Cauwenberghs G. Dry and noncontact EEG sensors for mobile brain-computer interfaces. *IEEE Trans Neural Syst Rehabil Eng* 2012;20(2):228–35. <http://dx.doi.org/10.1109/TNSRE.2011.2174652>.
- Chi YM, Wang Y, Wang YT, Jung TP, Kerth T, Cao Y. *A practical mobile dry EEG system for human computer interfaces*. In: Schmorow DD, Fidopiastis CM, editors. *Foundations of augmented cognition*. Heidelberg: Springer; 2013. p. 649–55.
- Chuang AT, Margo CE, Greenberg PB. Retinal implants: a systematic review. *Br J Ophthalmol* 2014. <http://dx.doi.org/10.1136/bjophthalmol-2013-303708>.
- Collinger JL, Kryger MA, Barbara R, Betler T, Bowsher K, Brown EH, et al. Collaborative approach in the development of high-performance brain-computer interfaces for a neuroprosthetic arm: translation from animal models to human control. *Clin Transl Sci* 2014;7:52–9. <http://dx.doi.org/10.1111/cts.12086>.
- Collinger JL, Wodlinger B, Downey JE, Wang W, Tyler-Kabara EC, Weber DJ, et al. High-performance neuroprosthetic control by an individual with tetraplegia. *Lancet* 2013;381(9866):557–64. [http://dx.doi.org/10.1016/S0140-6736\(12\)61816-9](http://dx.doi.org/10.1016/S0140-6736(12)61816-9).
- Coyle D, Principe J, Lotte F, Nijholt A. Guest editorial: brain/neuronal-computer game interfaces and interaction. *IEEE Trans Comput Intell AI Games* 2013;5(2):77–81. <http://dx.doi.org/10.1109/TCAIG.2013.2264736>.
- Dadarlat MC, O'Doherty JE, Sabes PN. A learning-based approach to artificial sensory feedback: intracortical microstimulation replaces and augments vision. In: 6th International IEEE EMBS Conference on Neural Engineering; 2013.
- Davis G, McConnell C, Popovic D, Berka C, Korszen S. Soft, embeddable dry EEG sensors for real world applications. In: Schmorow DD, Fidopiastis CM, editors. *Foundations of augmented cognition*. Berlin/Heidelberg: Springer; 2013. p. 269–78.
- Deadwyler SA, Berger TW, Sweatt AJ, Song D, Chan RH, Opris I, et al. Donor/recipient enhancement of memory in rat hippocampus. *Front Syst Neurosci* 2013;7:120. <http://dx.doi.org/10.3389/fnsys.2013.00120>.
- Defense Advanced Research Projects Agency. Driving technological surprise: DARPA's mission in a changing world; 2013 <http://www.darpa.mil/WorkArea/DownloadAsset.aspx?id=2147486475>
- Diester I, Kaufman MT, Mogri M, Pashae R, Goo W, Yizhar O, et al. An optogenetic toolbox designed for primates. *Nat Neurosci* 2011;14(3):387–97. <http://dx.doi.org/10.1038/nn.2749>.
- Dorrance DW. Patent No. US1042413 A. United States; 1912.
- Doud AJ, Lucas JP, Pisansky MT, He B. Continuous three-dimensional control of a virtual helicopter using a motor imagery based brain-computer interface. *PLoS ONE* 2011;6(10):e26322. <http://dx.doi.org/10.1371/journal.pone.0026322>.
- Fetterhoff D, Opris I, Simpson SL, Deadwyler SA, Hampson RE, Kraft RA. Multifractal analysis of information processing in hippocampal neural ensembles during working memory under $\Delta 9$ -tetrahydrocannabinol administration. *J Neurosci Methods* 2014. <http://dx.doi.org/10.1016/j.jneumeth.2014.07.013>, pii: S0165-0270(14)00264-7.
- Fetz EE. Operant conditioning of cortical unit activity. *Science* 1969;163(3870):955–8.
- Foster JD, Nuyujukian P, Freifeld O, Ryu SI, Black MJ, Shenoy KV. A framework for relating neural activity to freely moving behavior. In: *Conf Proc IEEE Eng Med Biol Soc*; 2012. p. 2736–9. <http://dx.doi.org/10.1109/EMBC.2012.6346530>.
- Furman B. *Progress in prosthetics*. Washington, DC: US Department of Education, Health and Welfare; 1962.
- Gage GJ, Ludwig KA, Otto KJ, Ionides EL, Kipke DR. Naïve coadaptive cortical control. *J Neural Eng* 2005;2(2):52–63.
- Géléoc GS, Holt JR. Sound strategies for hearing restoration. *Science* 2014;344(6184):1241062. <http://dx.doi.org/10.1126/science>.
- Gilja V, Chestek CA, Diester I, Henderson JM, Deisseroth K, Shenoy KV. Challenges and opportunities for next-generation intracortically based neural prostheses. *IEEE Trans Biomed Eng* 2011;58(7):1891–9. <http://dx.doi.org/10.1109/TBME.2011.2107553>.
- Graimann B, Allison B, Pfurtscheller G. *Brain-computer interfaces: a gentle introduction*. In: Graimann B, Allison B, Pfurtscheller G, editors. *Brain-computer interfaces*. Berlin: Springer; 2010. p. 1–27.
- Halford J, Waters CG, Martz G, Kutluay E, Dean BC, Soussou W. *Quality assessment of electroencephalography obtained from a "dry electrode" system in veterans*. In: 67th Annual Meeting of the American Epilepsy Society; 2013. p. 3.084.
- Hampson RE, Gerhardt GA, Marmarelis V, Song D, Opris I, Santos L, et al. Facilitation and restoration of cognitive function in primate prefrontal cortex by a neuroprosthesis that utilizes minicolumn-specific neural firing. *J Neural Eng* 2012c;9(5):056012.
- Hampson RE, Song D, Chan RH, Sweatt AJ, Riley MR, Gerhardt GA, et al. A nonlinear model for hippocampal cognitive prosthesis: memory facilitation by hippocampal ensemble stimulation. *IEEE Trans Neural Syst Rehabil Eng* 2012a;20(2):184–97. <http://dx.doi.org/10.1109/TNSRE.2012.2189163>.
- Hampson RE, Song D, Chan RH, Sweatt AJ, Riley MR, Goonawardena AV, et al. Closing the loop for memory prosthesis: detecting the role of hippocampal neural ensembles using nonlinear models. *IEEE Trans Neural Syst Rehabil Eng* 2012b;20(4):510–25. <http://dx.doi.org/10.1109/TNSRE.2012.2190942>.
- Hampson RE, Song D, Opris I, Santos LM, Shin DC, Gerhardt GA, et al. Facilitation of memory encoding in primate hippocampus by a neuroprosthesis that promotes task-specific neural firing. *J Neural Eng* 2013;10(6):066013. <http://dx.doi.org/10.1088/1741-2560/10/6/066013>.
- Hauschild M, Mulliken GH, Fineman I, Loeb GE, Andersen RA. Cognitive signals for brain-machine interfaces in posterior parietal cortex include continuous 3D trajectory commands. *Proc Natl Acad Sci USA* 2012;109(42):17075–80. <http://dx.doi.org/10.1073/pnas.1215092109>.
- He W, Bellamkonda RV. A molecular perspective on understanding and modulating the performance of chronic central nervous system (CNS) recording electrodes. In: Reichert WM, editor. *Indwelling neural implants: strategies for contending with the in vivo environment*. Boca Raton, FL: CRC Press; 2008 [Chapter 6]. Available from: <http://www.ncbi.nlm.nih.gov/books/NBK3930/>
- Hebert J, Olson J, Morhart M, Dawson M, Marasco P, Kuiken T, et al. Novel targeted sensory reinnervation technique to restore functional hand sensation after transhumeral amputation. *IEEE Trans Neural Syst Rehabil Eng* 2013. <http://dx.doi.org/10.1109/TNSRE.2013.2294907>.
- Huber DJ, Khosla D, Chen Y, Van Buer DJ, Martin K. Low power multi-camera system and algorithms for automated threat detection. *Motion Imagery Technologies, Best Practices, and Workflows for Intelligence, Surveillance, and Reconnaissance (ISR), and Situational Awareness*. *Proc SPIE* 2013;8740. <http://dx.doi.org/10.1117/12.2016104>, 874006 13.
- Hung CP, Kreiman G, Poggio T, DiCarlo JJ. *Fast readout of object identity from macaque inferior temporal cortex*. *Science* 2005;310(5749):863–6.
- Jacobs M, Premji A, Nelson AJ. Plasticity-inducing TMS protocols to investigate somatosensory control of hand function. *Neural Plast* 2012;2012:350574. <http://dx.doi.org/10.1155/2012/350574>.
- Johannes MS, Bigelow JD, Burck JM, Harshbarger SD, Kozlowski MV, Van Doren T. *An overview of the developmental process for the modular prosthetic limb*. *Johns Hopkins APL Tech Dig* 2011;30(3):207–16.
- Johnson LA, Wander JD, Sarma D, Su DK, Fetz EE, Ojemann JG. Direct electrical stimulation of the somatosensory cortex in humans using electrocorticography electrodes: a qualitative and quantitative report. *J Neural Eng* 2013;10(3):036021. <http://dx.doi.org/10.1088/1741-2560/10/3/036021>.
- Judy JW. Neural interfaces for upper-limb prosthesis control: opportunities to improve long-term reliability. *IEEE Pulse* 2012;3(2):57–60. <http://dx.doi.org/10.1109/MPUL.2011.2181026>.
- Kar K, Krekelberg B. Transcranial electrical stimulation over visual cortex evokes phosphene with a retinal origin. *J Neurophysiol* 2012;108(8):2173–8. <http://dx.doi.org/10.1152/jn.00505.2012>.
- Karumbaiah L, Saxena T, Carlson D, Patil K, Patkar R, Gaupp EA, et al. Relationship between intracortical electrode design and chronic recording function. *Biomaterials* 2013;34(33):8061–74. <http://dx.doi.org/10.1016/j.biomaterials.2013.07.016>.
- Kerr CC, Neymotin SA, Chadderdon GL, Fietkiewicz CT, Francis JT, Lytton WW. Electrostimulation as a prosthesis for repair of information flow in a computer model of neocortex. *IEEE Trans Neural Syst Rehabil Eng* 2012;20(2):153–60. <http://dx.doi.org/10.1109/TNSRE.2011.2178614>.
- Khosla D, Bhattacharyya R, Tasinga P, Huber DJ. Optimal detection of objects in images and videos using electroencephalography (EEG). *Signal Processing, Sensor Fusion, and Target Recognition XX*. *Proc SPIE* 2011;8050. <http://dx.doi.org/10.1117/12.883586>, 80501C-1.
- Khosla D, Chen Y, Huber DJ, Van Buer DJ, Kim K, Cheng SY. Real-time, low power neuromorphic hardware for autonomous object recognition. *Airborne Intelligence, Surveillance, Reconnaissance (ISR) Systems and Applications X*. *Proc SPIE* 2013;8713:871313. <http://dx.doi.org/10.1117/12.2015944>.
- Larson PS, Cheung SW. Deep brain stimulation in area LC controllably triggers auditory phantom percepts. *Neurosurgery* 2012;70(2):398–405. <http://dx.doi.org/10.1227/NEU.0b013e3182320ab5>, discussion 405–6.
- Lyle RC. *A performance test for assessment of upper limb function in physical rehabilitation treatment and research*. *Int J Rehabil Res* 1981;4(4):483–92.
- Macdonald JS, Mathan S, Yeung N. Trial-by-trial variations in subjective attentional state are reflected in ongoing prestimulus EEG alpha oscillations. *Front Psychol* 2011;2:82. <http://dx.doi.org/10.3389/fpsyg.2011.00082>.
- Mahmoudi B, Sanchez JC. A symbiotic brain-machine interface through value-based decision making. *PLoS ONE* 2011;6(3):e14760. <http://dx.doi.org/10.1371/journal.pone.0014760>.
- Makin JG, Fellows MR, Sabes PN. Learning multisensory integration and coordinate transformation via density estimation. *PLoS Comput Biol* 2013;9(4):e1003035. <http://dx.doi.org/10.1371/journal.pcbi.1003035>.
- Marsh B, Tarigoppula A, Chen C, Francis J. *Sensorimotor reward modulation during motion and observation used to implement an actor-critic brain machine interface*. In: *NCM 23rd Annual Meeting*; 2013.
- Marshall D, Coyle D, Wilson S, Callaghan M. Games, gameplay, and BCI: the state of the art. *IEEE Trans Comput Intell AI Games* 2013;5(2):82–99. <http://dx.doi.org/10.1109/TCAIG.2013.2263555>.
- Marx V. Neuroscience waves to the crowd. *Nat Methods* 2013;10:1069–74. <http://dx.doi.org/10.1038/nmeth.2695>.
- May T, Ozden I, Agha N, Wagner F, Brush B, Borton DA, et al. *Behavioral report of optogenetic stimulation of somatosensory cortex hand representation in*

- non-human primates. In: Society for Neuroscience Annual Meeting; 2013. p. 644.12/NN1.
- National Spinal Cord Injury Statistical Center. *Spinal cord injury facts and figures at a glance*; 2013, Birmingham, AL.
- Neymotin SA, Chadderdon GL, Kerr CC, Francis JT, Lytton WW. Reinforcement learning of two-joint virtual arm reaching in a computer model of sensorimotor cortex. *Neural Comput* 2013;12:3263–93, <http://dx.doi.org/10.1162/NECO.a.00521>.
- O'Doherty JE, Lebedev MA, Ifft PJ, Zhuang KZ, Shokur S, Bleuler H, et al. Active tactile exploration using a brain-machine-brain interface. *Nature* 2011;479(7372):228–31, <http://dx.doi.org/10.1038/nature10489>.
- O'Donnell FL. *Medical surveillance monthly report*. Silver Spring, MD: Armed Forces Health Surveillance Center; 2012.
- Opris I, Fuqua JL, Gerhardt GA, Hampson RE, Deadwyler SA. Prefrontal cortical recordings with biomorphic MEAs reveal complex columnar-laminar microcircuits for BCI/BMI implementation. *J Neurosci Methods* 2014, <http://dx.doi.org/10.1016/j.jneumeth.2014.05.029>, pii: S0165-0270(14)00197-6.
- Opris I, Fuqua JL, Huetttl PF, Gerhardt GA, Berger TW, Hampson RE, et al. Closing the loop in primate prefrontal cortex: inter-laminar processing. *Front Neural Circuits* 2012;6:88, <http://dx.doi.org/10.3389/fncir.2012.00088>.
- Ortiz-Catalan M, Bränemark R, Håkansson B, Delbeke J. On the viability of implantable electrodes for the natural control of artificial limbs: review and discussion. *Biomed Eng Online* 2012;11:33, <http://dx.doi.org/10.1186/1475-925X-11-33>.
- Ozden I, Wang J, Lu Y, May T, Lee J, Goo W, et al. A coaxial optrode as multifunction write-read probe for optogenetic studies in non-human primates. *J Neurosci Methods* 2013;219(1):142–54, <http://dx.doi.org/10.1016/j.jneumeth.2013.06.011>.
- Pasquina PF, Evangelista M, Carvalho AJ, Lockhart J, Griffin S, Nanos G, et al. First-in-man demonstration of a fully implanted myoelectric sensors system to control an advanced electromechanical prosthetic hand. *J Neurosci Methods* 2014, <http://dx.doi.org/10.1016/j.jneumeth.2014.07.016>, pii: S0165-0270(14)00267-2.
- Pei X, Barbour DL, Leuthardt EC, Schalk G. Decoding vowels and consonants in spoken and imagined words using electrocorticographic signals in humans. *J Neural Eng* 2011;8(4):046028, <http://dx.doi.org/10.1088/1741-2560/8/4/046028>.
- Putrino D, Wong YT, Weiss A, Pesarin B. A training platform for many-dimensional prosthetic devices using a virtual reality environment. *J Neurosci Methods* 2014, <http://dx.doi.org/10.1016/j.jneumeth.2014.03.010>, pii: S0165-0270(14)00098-3.
- Pohlmeier EA, Mahmoudi B, Geng S, Prins NW, Sanchez JC. Using reinforcement learning to provide stable brain-machine interface control despite neural input reorganization. *PLOS ONE* 2014;9(1):e87253, <http://dx.doi.org/10.1371/journal.pone.0087253>.
- Prasad A, Sanchez JC. Quantifying long-term microelectrode array functionality using chronic in vivo impedance testing. *J Neural Eng* 2012;9(2):026028, <http://dx.doi.org/10.1088/1741-2560/9/2/026028>.
- Prasad A, Xue Q, Dieme R, Sankar V, Mayrand R, Nishida T, et al. Abiotic-biotic characterization of Pt/Ir microelectrode arrays in chronic implants. *Front Neuroeng* 2014, <http://dx.doi.org/10.3389/fneng.2014.00002>.
- Qian M, Aguilar M, Zachary KN, Privitera C, Klein S, Carney T, et al. Decision-level fusion of EEG and pupil features for single-trial visual detection analysis. *IEEE Trans Biomed Eng* 2009;56(7):1929–37, <http://dx.doi.org/10.1109/TBME.2009.2016670>.
- Rahman A, Reato D, Arlotti M, Gasca F, Datta A, Parra LC, et al. Cellular effects of acute direct current stimulation: somatic and synaptic terminal effects. *J Physiol* 2013;591(Pt 10):2563–78, <http://dx.doi.org/10.1113/jphysiol.2012.247171>.
- Raphael G, Berka C, Popovic D, Chung GK, Nagashima SO, Behneman A, et al. I-NET: interactive neuro-educational technology to accelerate skill learning. In: *Conf Proc IEEE Eng Med Biol Soc*; 2009. p. 4803–7, <http://dx.doi.org/10.1109/IEMBS.2009.5332638>.
- Resnik L, Klinger SL, Etter K. The DEKA Arm: its features, functionality, and evolution during the Veterans Affairs Study to optimize the DEKA Arm. *Prosthet Orthot Int* 2013, <http://dx.doi.org/10.1177/0309364613506913>.
- Roset SA, Gonzalez HF, Sanchez JC. Development of an EEG based reinforcement learning brain-computer interface system for rehabilitation. In: *Conf Proc IEEE Eng Med Biol Soc*; 2013. p. 1563–6, <http://dx.doi.org/10.1109/EMBC.2013.6609812>.
- Sajda P, Gerson A, Parra L. High-throughput image search via single-trial event detection in a rapid serial visual presentation task. In: *Proc. 1st Inter. IEEE EMBS Conf. on Neural Engineering*. Capri Island, Italy: IEEE; 2003. p. 7–10, <http://dx.doi.org/10.1109/CNE.2003.1196297>.
- Sajda P, Parra LC, Christoforou C, Hanna B, Bahlmann C, Wang J, et al. In a blink of an eye and a switch of a transistor: cortically-coupled computer vision. *Proc IEEE* 2010;98(3):462–78, <http://dx.doi.org/10.1109/JPROC.2009.2038406>.
- Sanchez J, Lytton W, Carmenta J, Principe J, Fortes J, Barbour R, et al. Dynamically repairing and replacing neural networks: using hybrid computational and biological tools. *IEEE Pulse* 2012;3(1):57–9, <http://dx.doi.org/10.1109/MPUL.2011.2175640>.
- Saxena T, Karumbaiah L, Gaupp EA, Patkar R, Patil K, Betancur M, et al. The impact of chronic blood-brain barrier breach on intracortical electrode function. *Biomaterials* 2013;34(20):4703–13, <http://dx.doi.org/10.1016/j.biomaterials.2013.03.007>.
- Schiller PH, Slocum WM, Kwak MC, Kendall GL, Tehovnik EJ. New methods devised specify the size and color of the spots monkeys see when striate cortex (area V1) is electrically stimulated. *Proc Natl Acad Sci USA* 2011;108(43):17809–14, <http://dx.doi.org/10.1073/pnas.1108337108>.
- Shenoy KV, Sahani M, Churchland MM. Cortical control of arm movements: a dynamical systems perspective. *Annu Rev Neurosci* 2013;36:337–59, <http://dx.doi.org/10.1146/annurev-neuro-062111-150509>.
- Shenoy K, Nurmikko AV. Brain models enabled by next-generation neurotechnology: using multiscale and multimodal models. *IEEE Pulse* 2012;3(2):31–6, <http://dx.doi.org/10.1109/MPUL.2011.2181021>.
- Song D, Chan RH, Marmarelis VZ, Hampson RE, Deadwyler SA, Berger TW. Nonlinear dynamic modeling of spike train transformations for hippocampal-cortical prostheses. *IEEE Trans Biomed Eng* 2007;54(6 Pt 1):1053–66.
- Song D, Chan RH, Marmarelis VZ, Hampson RE, Deadwyler SA, Berger TW. Nonlinear modeling of neural population dynamics for hippocampal prostheses. *Neural Netw* 2009;22(9):1340–51, <http://dx.doi.org/10.1016/j.neunet.2009.05.004>.
- Song D, Robinson BS, Chan RH, Marmarelis VZ, Opris I, Hampson RE, et al. Identification of functional synaptic plasticity from spiking activities using nonlinear dynamical modeling. *J Neurosci Methods* 2014, <http://dx.doi.org/10.1016/j.jneumeth.2014.09.023>, pii: S0165-0270(14)00348-3.
- Song W, Kerr CC, Lytton WW, Francis JT. Cortical plasticity induced by spike-triggered microstimulation in primate somatosensory cortex. *PLOS ONE* 2013;8(3):e57453, <http://dx.doi.org/10.1371/journal.pone.0057453>.
- Stevens RH, Galloway TL, Wang P, Berka C. Cognitive neurophysiologic synchronies: what can they contribute to the study of teamwork? *Hum Factors* 2012;54(4):489–502.
- Stinner DJ, Burns TC, Kirk KL, Ficke JR. Return to duty rate of amputee soldiers in the current conflicts in Afghanistan and Iraq. *J Trauma* 2010;68(6):1476–9, <http://dx.doi.org/10.1097/TA.0b013e3181bb9a6c>.
- Tabot GA, Dammann JF, Berg JA, Tenore FV, Boback JL, Vogelstein RJ, et al. Restoring the sense of touch with a prosthetic hand through a brain interface. *Proc Natl Acad Sci USA* 2013;110(45):18279–84, <http://dx.doi.org/10.1073/pnas.1221113110>.
- Thota AK, Kuntaegowdanahalli S, Starosciak AK, Abbas JJ, Orbay J, Horch KW, et al. A system and method to interface with multiple groups of axons in several fascicles of peripheral nerves. *J Neurosci Methods* 2014, <http://dx.doi.org/10.1016/j.jneumeth.2014.07.020>, pii: S0165-0270(14)00271-4.
- Thurlings ME, van Erp JB, Brouwer AM, Werkhoven PJ. EEG-based navigation from a human factors perspective. In: Tan DS, Nijholt A, editors. *Brain-computer interfaces, human-computer interaction series*. London: Springer-Verlag; 2010. p. 71–86, http://dx.doi.org/10.1007/978-1-84996-272-8_5.
- Tien LW, Wu F, Tang-Schomer MD, Yoon E, Omenetto FG, Kaplan DL. Silk as a multifunctional biomaterial substrate for reduced glial scarring around brain-penetrating electrodes. *Adv Funct Mater* 2013;23(25):3185–93, <http://dx.doi.org/10.1002/adfm.201203716>.
- U.S. Food and Drug Administration. Driving biomedical innovation: initiatives to improve products for patients; 2011a, Available from: www.fda.gov/innovation.
- U.S. Food and Drug Administration. FDA launches medical device innovation initiative [Press release]; 2011b, Retrieved from <http://www.fda.gov/newsevents/newsroom/pressannouncements/ucm24629.htm>.
- U.S. Government Accountability Office. VA mental health: number of veterans receiving care, barriers faces, and efforts to increase access. report to the ranking member. Committee on Veterans' Affairs, House of Representatives; 2011.
- Vetter RJ, Williams JC, Hetke JF, Nunamaker EA, Kipke DR. Chronic neural recording using silicon-substrate microelectrode arrays implanted in cerebral cortex. *IEEE Trans Biomed Eng* 2004;51(6):896–904.
- Vidal JJ. Toward direct brain-computer communication. *Annu Rev Biophys Bioeng* 1973;2(1):157–80.
- Vidal JJ. Real-time detection of brain events in EEG. *Proc IEEE* 1977;65(5):633–41.
- Weiden M, Khosla D, Keegan M. Electroencephalographic detection of visual saliency of motion towards a practical brain-computer interface for video analysis. *ICMI'12*. In: *Proceedings of the 14th ACM International Conference on Multimodal Interaction*. New York, NY: ACM; 2012. p. 601–6, <http://dx.doi.org/10.1145/2388676.2388800>.
- Zaaimi B, Ruiz-Torres R, Solla SA, Miller LE. Multi-electrode stimulation in somatosensory cortex increases probability of detection. *J Neural Eng* 2013;10(5):056013, <http://dx.doi.org/10.1088/1741-2560/10/5/056013>.
- Zalocusky K, Deisseroth K. Optogenetics in the behaving rat: integration of diverse new technologies in a vital animal model. *Optogenetics* 2013;1:1–17, <http://dx.doi.org/10.2478/optog-2013-0001>.

US Department of Defense

FISCAL YEAR 2018 BUDGET REQUEST



Office of the Under Secretary of Defense (Comptroller) / CFO

MAY 2017

Rebuilding the U.S. Armed Forces

- Get Ready
 - FY 2017 added resources to improve near term readiness
- Get Balanced
 - FY 2018 budget request builds on readiness improvements in the FY 2017 budget and adds resources to balance the force
- Get Bigger and More Lethal
 - The goal in FY 2019 will be to sustain the gains in FY 2017/FY 2018 and, informed by the new defense strategy, build further to achieve a bigger more lethal and ready force



FY 2018 Budget Request

Base Budget Request:	\$574.5 billion
Overseas Contingency Operations (OCO):	<u>\$64.6 billion</u>
Total	\$639.1 billion

- Base budget request is \$52 billion above DoD's share of the FY 2018 Defense budget cap in current law
- Must increase the Defense budget cap in order to adequately protect U.S. national security
- Since enactment of the BCA, the world has become a more dangerous place with rising terrorism and more aggressive potential adversaries
- Under the BCA, the military has become smaller, readiness has eroded, and modernization has been deferred
- This budget begins to balance the Defense program and establishes a foundation for rebuilding the U.S. military into a more capable, lethal and ready joint force

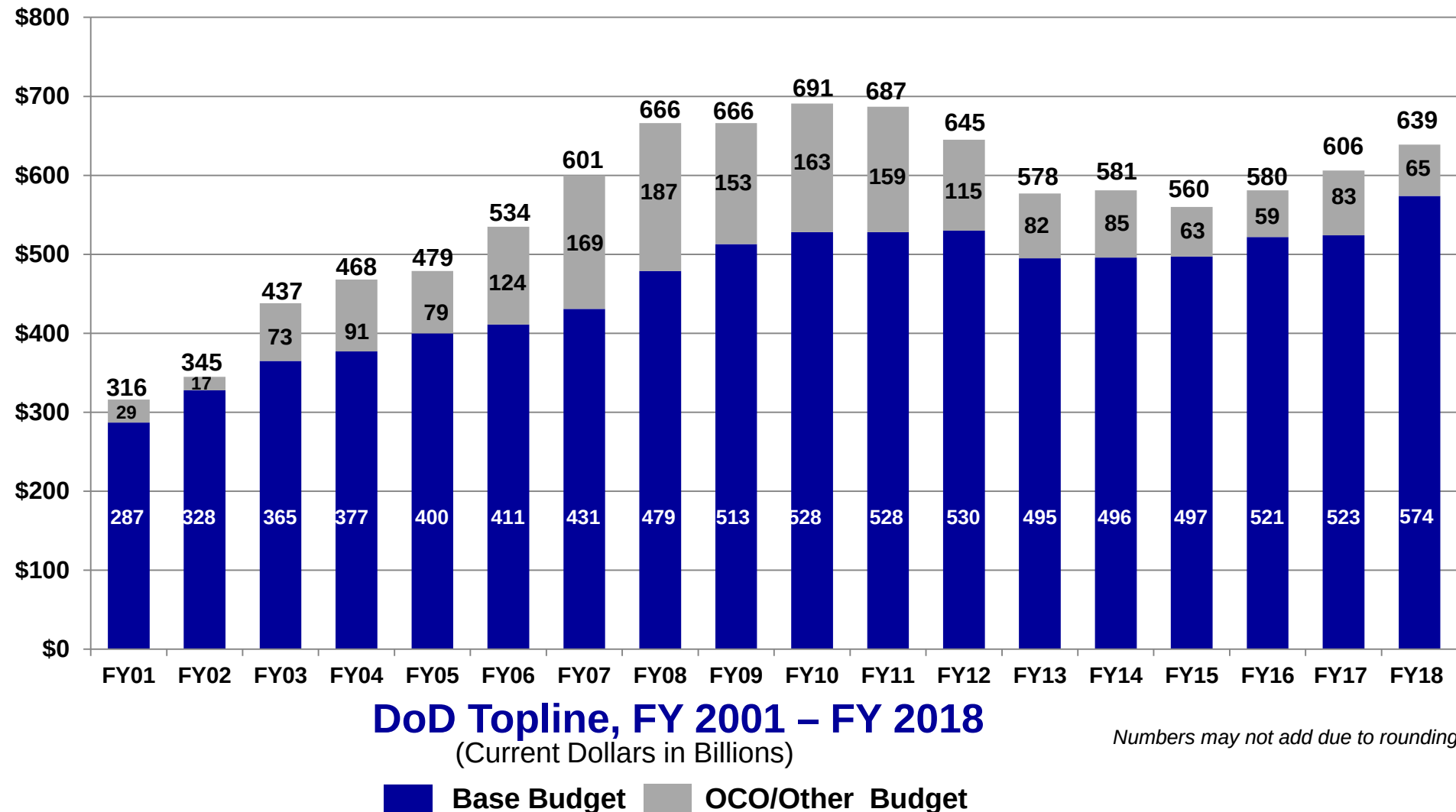
FY 2018 Themes

- Improving warfighter readiness
 - More aircraft in the air, ships at sea, troops in the field, and munitions on hand to rebuild the current force
- Address evolving national security challenges
 - Retain counterterrorism/counter insurgency competencies
 - Preserve competitive advantage versus major adversaries
 - Sustain capability development for new warfighter concepts
- Recapitalize and modernize nuclear enterprise
- Prioritize key investments in cyber and space capabilities
- Focus on innovation to maintain technological advantage
- Sustain the finest fighting force in the world
- Identify reforms to improve efficiencies and achieve cost savings



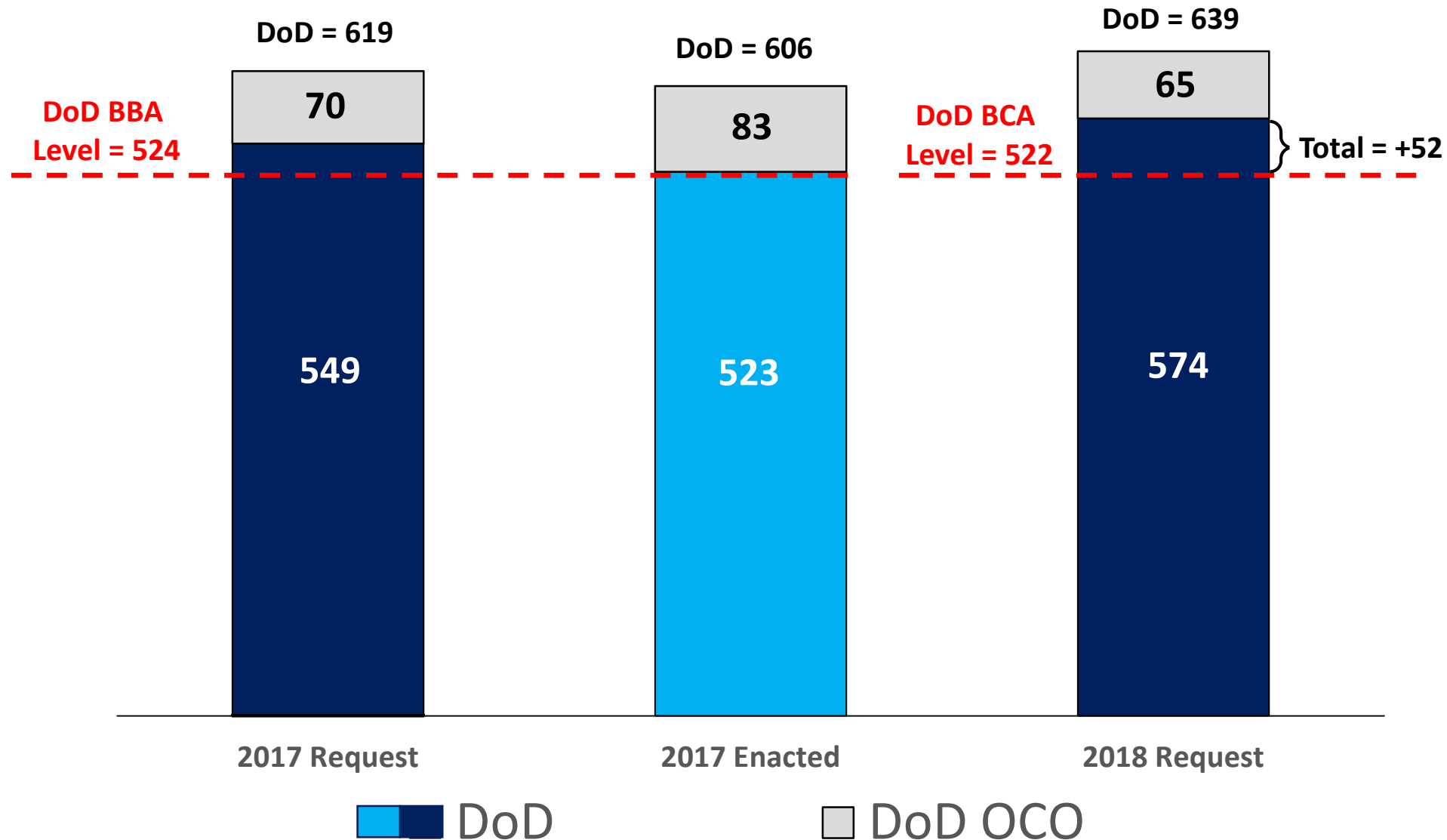
DoD Funding from 9/11 Through FY 2018 Request

(Discretionary Budget Authority)



Defense Budget Request

(\$ in Billions)



Numbers may not add due to rounding

Improving Warfighter Readiness

- Continues significant investments in training, maintenance, and modernization to restore near-term warfighting readiness while setting conditions for future, sustained comprehensive readiness
- Supports Combatant Command exercises and engagements to increase joint training capabilities
- Invests in critical aviation; munitions; and Intelligence, Surveillance, and Reconnaissance (ISR) capabilities in support of Combatant Command theater activities

FY 2018 enhances cross-cutting readiness investments



Restore Service Readiness

- **Army:**
 - Supports increased home station training and additional high-end collective training exercises, resulting in 19 combat training center rotations in 2018
 - Mitigates personnel gaps with the additional end strength to increase unit readiness
- **Navy:**
 - Funds ship maintenance and increases shipyard civilian personnel to improve throughput timelines to meet future deployments
 - Funds deployed flying hours while investing in maintenance and depot throughput to increase the number of available aircraft for training and deployments
- **Marine Corps:**
 - Funds forward deployed Special Purpose Marine Air Ground Task Forces and Unit Deployment Plan to sustain the DoD's Crisis Response Force
 - Invests in integrated training exercises, equipment reset, and modernization programs
- **Air Force:**
 - Invests in additional military end strength to fill critical gaps in pilot production and maintainer career fields
 - Balances readiness recovery, current weapons system sustainment, and modernization programs
- **USSOCOM:**
 - Accelerates precision strike and specialized air mobility enhancement, and expands airborne Intelligence, Surveillance, and Reconnaissance (ISR) capacity and capability
 - Supports expanded participation in regional training events, funds operational enhancements, and modernization of intelligence, targeting, and strike enablers

FY 2018 budget continues investment in readiness recovery

FY 2018 President's Budget Military End Strength

Military Component	PB18				PB17	Δ PB17-PB18
	FY 2016 ^{1/}	FY 2017 ^{2/}	FY 2018	Δ FY17-18	FY 2018	FY 2018
Active Components (AC)						
Army	475,400	476,000	476,000	--	450,000	+26,000
Navy	324,557	326,492	327,900	+1,408	322,200	+5,700
Marine Corps	183,604	184,426	185,000	+574	182,000	+3,000
Air Force	317,883	321,125	325,100	+3,975	317,000	+8,100
TOTAL AC	1,301,444	1,308,043	1,314,000	+5,957	1,271,200	+42,800
Reserve Components (RC)						
Army Reserve	198,395	199,000	199,000	--	195,000	+4,000
Navy Reserve	57,980	58,175	59,000	+825	58,900	+100
Marine Corps Reserve	38,453	38,940	38,500	-440	38,500	--
Air Force Reserve	69,364	69,000	69,800	+800	69,200	+600
Army National Guard	341,589	343,000	343,000	--	335,000	+8,000
Air National Guard	105,887	105,700	106,600	+900	105,700	+900
TOTAL RC	811,668	813,815	815,900	+2,085	802,300	+13,600
Army AC + RC	1,105,384	1,018,000	1,018,000	--	980,000	+38,000
Navy AC + RC	382,537	384,667	386,900	+2,233	381,100	+5,800
Marine Corps AC + RC	222,057	223,366	223,500	+134	220,500	+3,000
Air Force AC + RC	493,134	495,825	501,500	+5,675	491,900	+9,600
TOTAL AC + RC	2,113,112	2,121,858	2,129,900	+8,042	2,073,500	+56,400

1/ FY 2016 Actuals

2/ FY 2017 reflects request for additional appropriations projected end strength levels

Reverses end strength reductions – FY 2018 56.4K higher than PB17

Major Investments in the FY 2018 Budget

Aircraft

(Quantities/Dollars in Billions)

F-35 Joint Strike Fighter (USAF, USMC, USN)	70	\$10.8
KC-46 Tanker Replacement (Air Force)	15	\$3.1
F/A-18 Aircraft (Navy)	14	\$1.3
AH-64E Attack Helicopter (Army)	61	\$1.4
UH-60 Utility Helicopter (Army)	48	\$1.1
P-8A Aircraft (Navy)	7	\$1.6
MQ-4 Triton Unmanned Aerial Vehicle (Navy)	3	\$0.9
B-21 Long Range Strike Bomber (Air Force)	-	\$2.0

Shipbuilding

Virginia Class Submarine	2	\$5.5
DDG-51 AEGIS Destroyers	2	\$4.0
Littoral Combat ships (LCS)	1	\$1.2
CVN-78 Class Aircraft Carrier	1	\$4.6
LHA-6 Amphibious Assault Ship	-	\$1.7
Columbia Class Submarine - Advance Procurement	-	\$1.8

Space

Evolved Expendable Launch Vehicle (Air Force)	3	\$1.9
Space Based Infrared System (Air Force)	-	\$1.4

Major Investments in the FY 2018 Budget

(Continued)

Preferred Munitions	<u>(Quantities/Dollars in Billions)</u>	
Hellfire Missile	1,397	\$0.1
Joint Direct Attack Munition (JDAM)	12,822	\$0.4
Guided Multiple Launch Rocket System (GMLRS)	4,458	\$0.7
Advanced Precision Kill Weapon System (APKWS)	-	\$0.2
Small Diameter Bomb (SDB)	5,039	\$0.4
Tomahawk Missile	34	\$0.3
Ground Systems		
Joint Light Tactical Vehicle (Multi-service)	2,775	\$1.1
M-1 Tank Modifications (Army)	20	\$0.6
Amphibious Combat Vehicle (Marine Corps)	26	\$0.3
Armored Multi-Purpose Vehicle (Army)	42	\$0.4
Missile Defense Programs		
AEGIS SM-3 Missiles	40	\$1.6
Ground Based Midcourse	-	\$1.4

Focus on Technology Innovation

- Funds science and technology to further innovation (\$13.2 billion)
- Supports DoD, academic, and industry partnerships with initiatives like Army Research Lab Collaborative Research Alliances (\$58.7 million), Defense Innovation Unit-Experiment (DIUx) (\$54 million), and the pilot program with In-Q-Tel (\$60 million)
- Examples of technology initiatives
 - Alternative navigation technologies (e.g., Assured Positioning Navigation, and Timing (Army), Atomic Clocks with Enhanced Stability (ACES) (DARPA))
 - Directed energy weapons (e.g., Self-protect High Energy Laser Demonstrator (Air Force), High Energy Laser Tactical Vehicle Demonstrator (Army))
 - Electromagnetic spectrum technologies (e.g., Electromagnetic Maneuver & Control Capability (Navy))
 - High speed strike weapons (e.g., Hypersonic Flight Demonstrations (Air Force, DARPA), High-Speed Propulsion Technology (DARPA, Air Force, Navy))
 - Establishment of Hypersonics defeat program within the Missile Defense Agency
 - Low-cost unmanned systems (e.g., Low Cost Unmanned Air Systems Swarming Technology (LOCUST) (Navy), Perdix (Strategic Capabilities Office))
 - Investment across DoD to counter illicit Unmanned Aerial Systems (UAS) and other multi-domain unmanned or autonomous threats

DoD seeks to accelerate delivery of new capabilities

Facilities Investment

(Military Construction and Family Housing)

- Increases facilities investment by 25% (+\$2.0B) above the FY 2017 enacted base funded level (FY 17 \$7.8B; FY 18: \$9.8B)
 - Supports force readiness improvements:
 - Operational and training facilities (e.g., aircraft parking aprons, training ranges, beddown of new platforms such as F-35)
 - Maintenance and productions facilities (e.g., unmanned aerial vehicle hangar)
 - Remaining investments support:
 - Relocation of Marines from Japan to Guam
 - Recapitalization of schools and medical facilities
 - Improved Quality-of-Life (e.g., 9 troop housing projects)
- Seeks the authority to commence a new Base Realignment and Closure (BRAC) round in 2021
 - To reduce excess capacity and use the savings on higher priorities, such as readiness and modernization
 - DoD analyses indicate DoD has ~20% more infrastructure capacity than required
 - Based on prior BRAC experience, a new round focused on efficiency could save ~\$2B each year
 - To make the infrastructure more efficient

Reforming How the Department Does Business

- Continues to reduce DoD Major Headquarters Activities' staffs and overhead
 - Complies with FY 2016 NDAA to further reduce the MHA up to 25 percent
- Continues acquisition reform: Better Buying Power 3.0
- Service requirement review boards to evaluate Fourth Estate organizations' contracted services – consolidating contracts to reduce redundancy
- Sustains financial auditability improvements
 - Begin a full financial statement audit in FY 2018
 - Focus on remediating auditor findings
 - Identify solutions to impose business process and information technology changes

Budget continues to implement previous efficiencies

Reforming How the Department Does Business

(Continued)

- Implements FY 2017 NDAA Reforms
 - Effective February 1, 2018, reorganize the current Under Secretary of Defense for Acquisition, Technology and Logistics into two new Under Secretaries of Defense for:
 - Research and Engineering to be the chief technology officer with the mission of advancing technology and innovation
 - Acquisition and Sustainment to be the chief acquisition and sustainment officer with the mission of delivering and sustaining timely, cost-effective capabilities for the armed forces and the Department
 - Effective February 1, 2018, there is a Chief Management Officer with the mission of managing the business operations of the Department
 - Elevate Cyber Command
 - Strengthens cyber space as a warfighter domain
 - Streamline command and control of cyber space operations
 - Effective October 1, 2018, develop and implement a plan to reform the Administration of the Defense Health Agency and Military Treatment Facilities to reduce management costs, improve the delivery of healthcare, and enhance the Services' medical readiness capabilities

Continue to Pursue Compensation Reform

- Maintains the Health of Force through a competitive compensation package that reflects the unique demands and sacrifices of our service members
- Increases planned basic pay: 2.1% military pay raise
1.9% civilian pay raise
- Seeks modifications to the Military Health Care System
 - Continue to increase value (e.g., expand access through telehealth and additional nurse advice lines)
 - Exempt from cost share increase the medically retired and family members of those who die on active duty (i.e., eliminate participation fees and provide lower cost shares)
 - Seeks balanced approach to fiscal sustainability
 - Eliminate the grandfathering provision on cost share for members who joined before Jan 1, 2018.
 - Seeks additional changes to pharmacy co-pay structure to incentivize members to make the most effective choice (e.g., mail order vice retail)
- Seeks modest modifications to the Blended Retirement System to allow enlisted members who serve beyond 26 years to continue receiving government contributions for Thrift Savings Plan

Keeping Faith With Service Members and Families

- Maintains support for critical Family Assistance Programs
 - Warfighter & Family Services
 - Non-medical counseling support services
 - Financial Readiness
 - Joint Family Support Assistance through Military One Source
 - Family Advocacy Program
 - Military Spouse Education & Career Assistance
 - Morale, Recreation, & Welfare, such as fitness centers, libraries, recreations centers, and single service member programs
 - Tuition Assistance for Off-Duty Education Support
 - Child & Youth Programs serving over 1 million children
 - National Guard Youth Challenge
 - DoD Dependent Schools educating over 77 thousand students
 - Commissary Operations at 238 stores



Invests more than \$8 billion into supporting our families

FY 2018 Overseas Contingency Operations (OCO)

(Dollars in Billions)

Operation FREEDOM'S SENTINEL (Afghanistan) and Theater Posture	45.9
– Maintains in-country presence of 8,448 force level for train, advise and assist and counterterrorism efforts	
– Funds training and equipping of Afghan security forces, including Afghanistan aviation modernization (\$4.9 billion)	
– Includes other theater-wide support requirements and costs	
– Provides support for coalition forces (\$1.3 billion)	
• Operation INHERENT RESOLVE (Iraq and Syria)	13.0
– Supports ongoing operations against ISIS and maintains 5,765 force level	
– Includes training and equipping of Iraqi Security Forces and vetted Syrian opposition forces (\$1.8 billion)	
– Funds preferred munitions to maintain tempo of operations	
• European Reassurance Initiative (ERI)	4.8
– Supports the collective defense and security of NATO Allies, bolsters U.S. partners, and adds new capabilities to improve deterrence and warfighting effectiveness	
• Includes funding for train, equip, and advise efforts to build Ukrainian capacity (\$150 million)	
• Security Cooperation (SC)	<u>0.9</u>
– Builds partner capacity to conduct counterterrorism, crisis response and other SC missions through training, equipping and other activities (formerly Counterterrorism Partnerships Fund)	
TOTAL OCO REQUEST	64.6

Summary

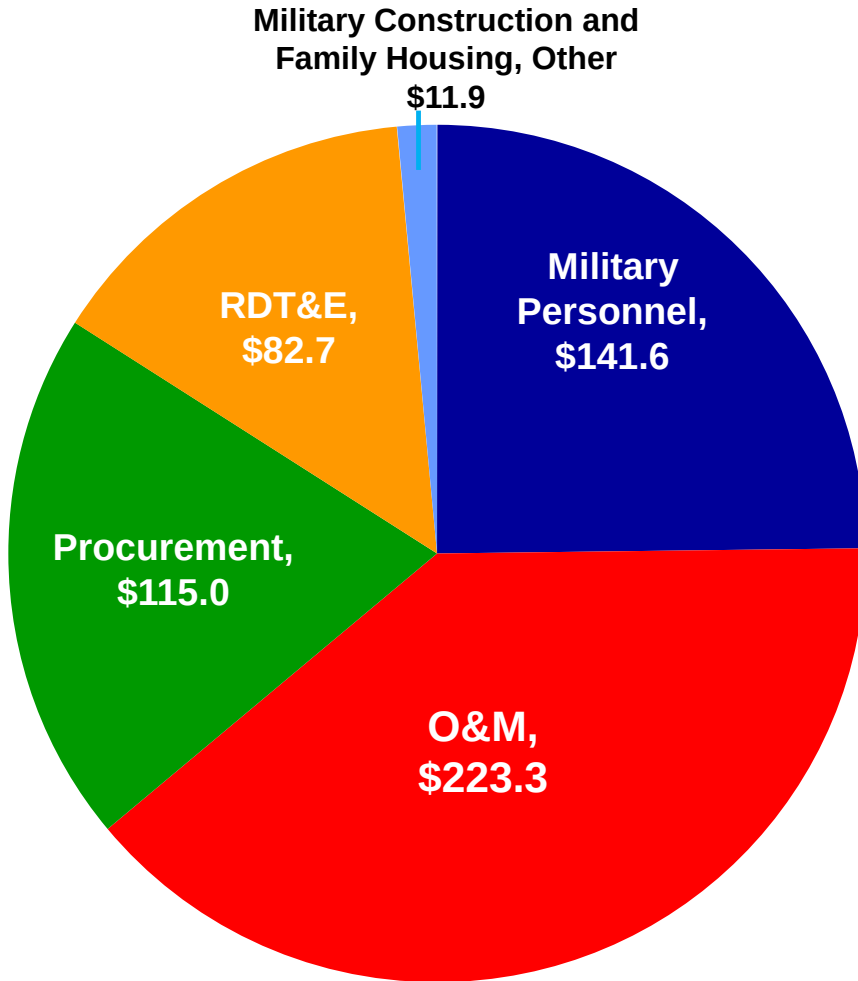
- Need to sustain and build on readiness improvements began in FY 2017
- Begin process of balancing the force to become bigger and more lethal
- Must increase Defense Budget Caps in order to support National Security Strategy and new Defense Strategy

Get ready. Get balanced. Get bigger and more lethal.

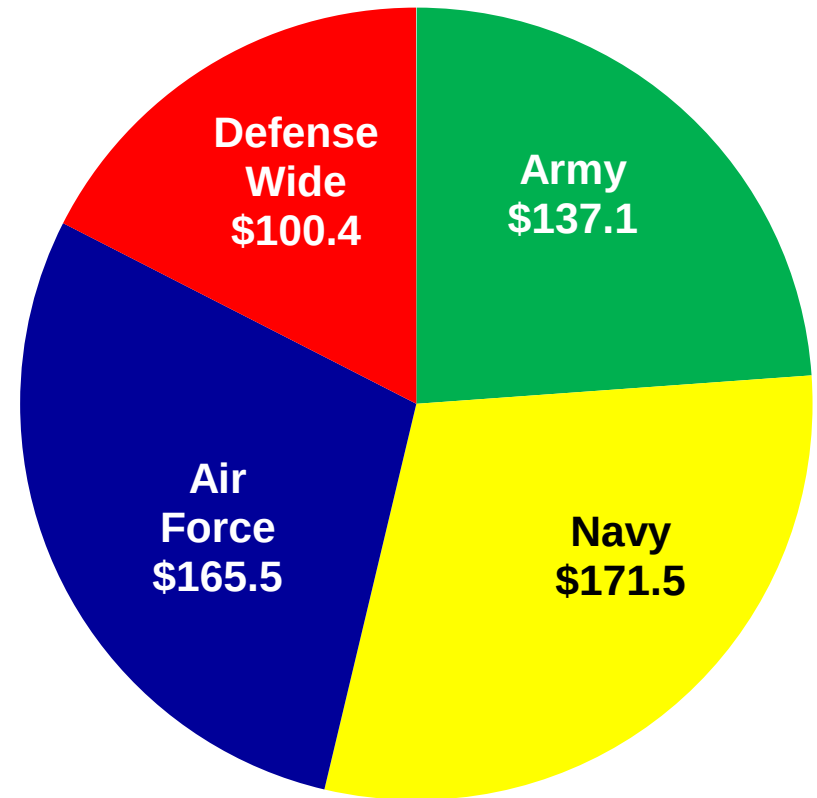


FY 2018 Base Funding

By Appropriation Title



By Military Department

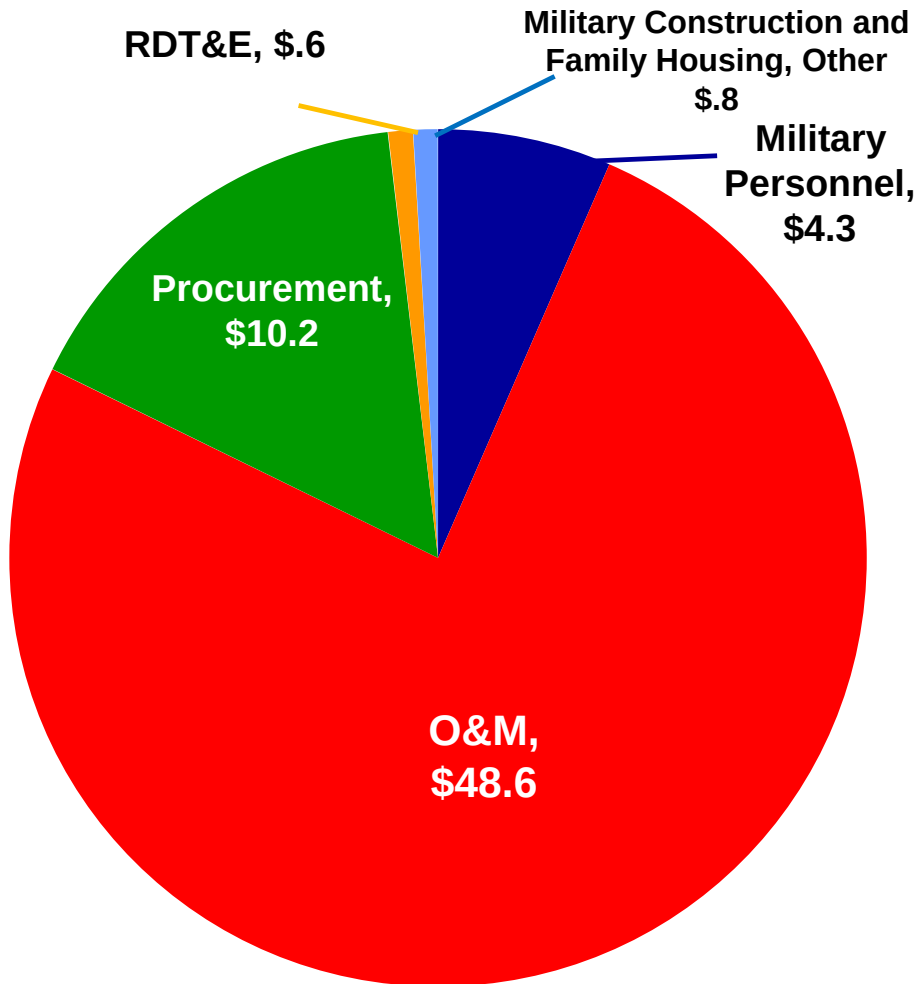


FY 2018 Request: \$574.5 billion

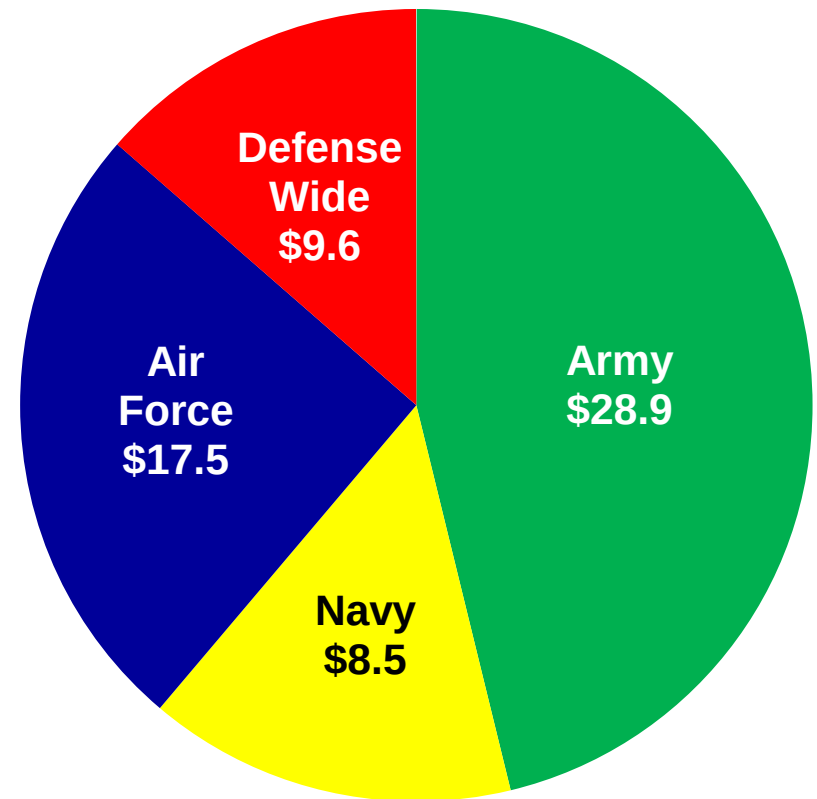
Numbers may not add due to rounding

FY 2018 OCO Funding

By Appropriation Title



By Military Department

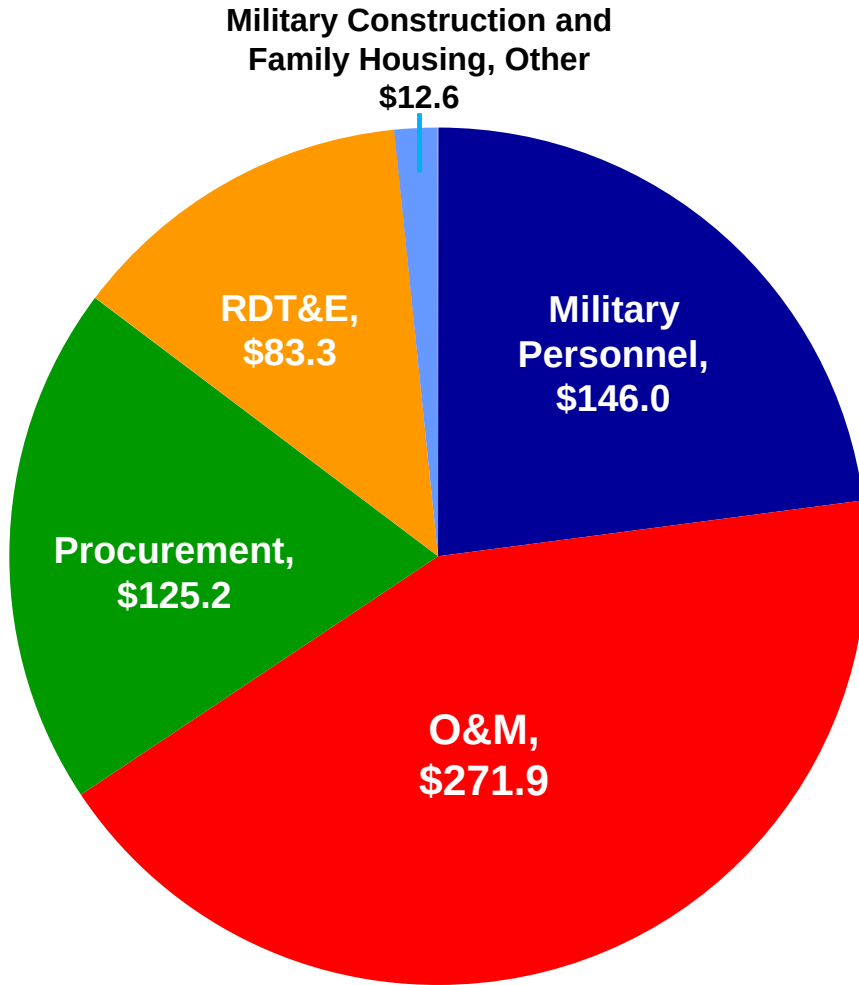


FY 2018 Request: \$64.6 billion

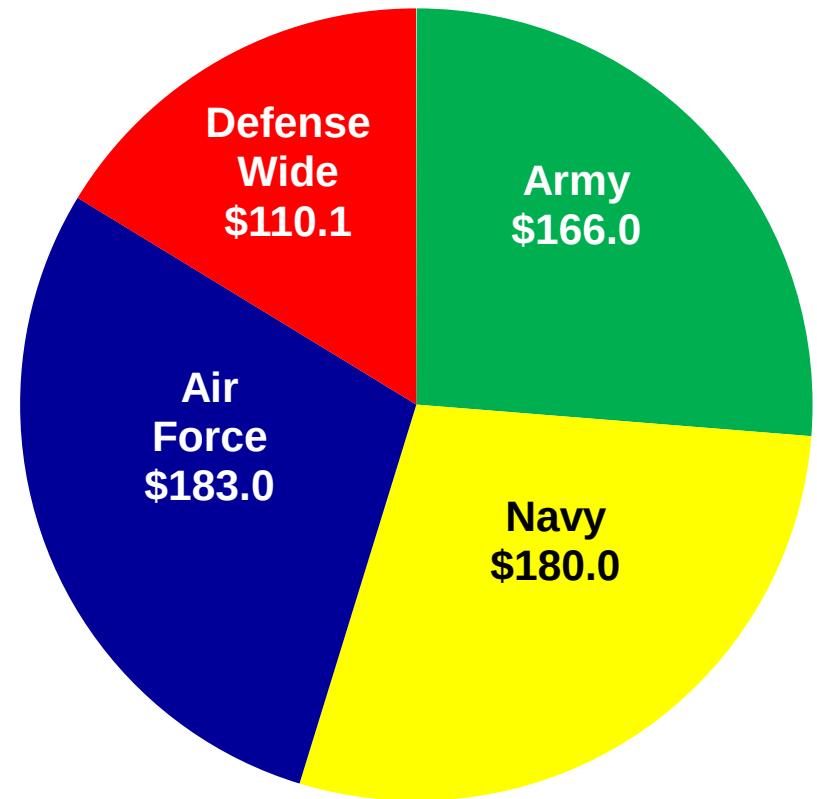
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FY 2018 Total Base and OCO Funding

By Appropriation Title



By Military Department

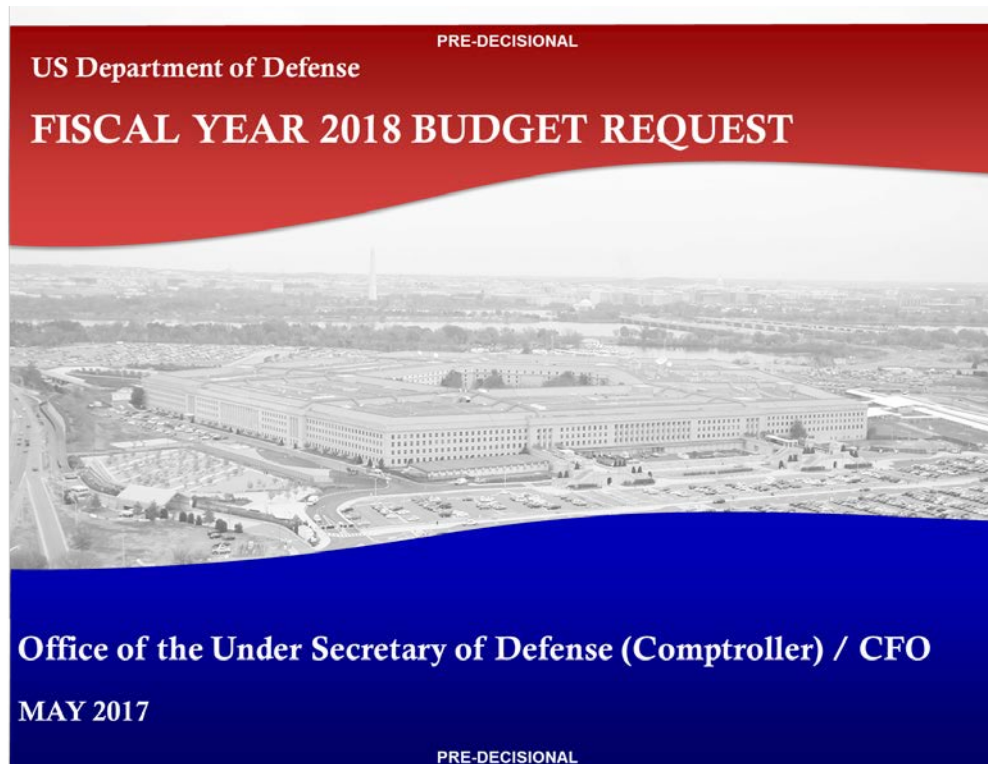


FY 2018 Request: \$639.1 billion

Numbers may not add due to rounding

For More Information

- Visit the website for the Office of the Under Secretary of Defense (Comptroller) at
 - www.budget.mil
 - Download the Department of Defense's FY 2018 Budget Request



DARPA 生物科技项目部署解析

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摘要 2014年,美国国防高级研究计划局(DARPA)宣布成立生物技术办公室(BTO),聚焦军人能力保持恢复与增强、生物系统的工程化应用、生物复杂性的规模化应用3个研究方向。在研项目由BTO成立时的23项发展到现在的31项,经费投入更为理性,研究重点更为聚焦。在文献调研基础上,利用专家咨询、综合分析、综合归纳等方法,解析了DARPA2016年以来的生物技术项目部署情况,表明其特点为:重点关注脑机接口领域,聚焦人机高效协同技术;着眼应对大规模流行性传染病暴发,重点研究快速诊断预防技术;高度关注生物安全威胁,重点研究安全防护对策;加快部署合成生物学研究,重点研究生物系统工程技术等。

关键词 美国国防高级研究计划局;生物科技项目;部署情况

2014年4月1日,美国国防高级研究计划局(DARPA)宣布成立生物技术办公室(BTO)^[1],目标是整合生物学、工程学和计算机科学等学科,将生物系统的巨大潜力应用到国家安全领域。这标志着美军已高度认识到生物技术的巨大军事价值,将生物技术提升到新的战略高度,并将其列为顶级优先发展领域之一。生物办公室成立以来,聚焦军人能力保持恢复与增强、生物系统的工程化应用、生物复杂性的规模化应用3个研究方向,在研项目已经由成立时的23项发展到现在的31项^[2](表1)。

1 生物技术项目部署

近10年来DARPA年度经费在28亿~32亿美元之间,呈现基本稳定的趋势,2015年为29.2亿美元,2016年为28.7亿美元,2017年为29.8亿美元,2018年为31.7

亿美元^[3]。生物技术领域研究经费逐渐稳定,2015年度生物技术领域为3.07亿美元,占DARPA年度经费的10.51%;2016年度为3.91亿美元,占比13.62%;2017年为4.15亿美元,占比13.93%;2018年度为3.90亿美元^[4],占比12.30%(图1)。

1.1 神经工程系统设计项目(NESD)将实现脑机交互

神经工程系统设计项目发布于2016年1月,是奥巴马总统大脑计划的组成部分,旨在开发植入式神经接口装置,在大脑和电子设备之间提供较高信号分辨率和数据传输带宽,通过将数字听觉或视觉信息以远远高于当前技术可能的分辨率和经验质量输入到大脑中,弥合生物与电子之间的鸿沟,使可完全植入的设备能和高达百万的神经元相连接,来补偿视力或听觉缺陷。它的目标是在生物相容性装置中实现通信连接,神经接口作为中介装置,将大脑神经元的电化学语言

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表1 DARPA在研主要项目
Table 1 Main research project of DARPA

序号	研究方向	具体项目
1	军人能力保持与恢复增强(15个)	可用于预防和治疗自主诊断技术(ADEPT)
2		战地医药(Battlefield Medicine)
3		时间生物学(Biochronicity)
4		类透析疗法(DLT)
5		电子处方(ElectRx)
6		手部本体感受和触感界面(HAPTIX)
7		可靠神经接口技术(RE-NET)
8		恢复主动记忆(RAM)
9		革命性假肢(Revolutionizing Prosthetics)
10		战略性社交模块(SSIM)
11		基于系统的神经技术疗法(SUBNETS)
12		目标神经可塑性训练(TNT)
13		宿主恢复力技术(THoR)
14		勇士织衣(Warrior Web)
15		伤口止血系统(WSS)
16	生物系统的工程化应用(7个)	生物代工厂(Living Foundries)
17		生物控制(Biological Control)
18		生物工程材料(ELM)
19		复杂环境下的生物鲁棒性(BRICS)
20		活体内纳米装置(IVN)
21		昆虫盟友(Insect Allies)
22		神经工程系统设计(NESD)
23	生物复杂性的规模化应用(9个)	微生理系统(MPS)
24		神经功能、行为、结构和技术(Neuro-FAST)
25		干预和共同预防及治疗(INTERCEPT)
26		大规模流行疾病预防(P3)
27		病原体捕食者(Pathogen Predators)
28		普罗米修斯(Prometheus)
29		预测(战胜病原体)[Prophecy (Pathogen Defeat)]
30		快速威胁评估(Rapid Threat Assessment)
31		安全基因(Safe Genes)

转换为信息技术语言的1和0。装置尺寸不大于1 cm³。研究除了面临项目硬件设备的挑战,还需要开发先进的数学和神经计算技术,首先将电子设备和皮层神经元之间的高清晰度感官信息转码,然后压缩传输数据,并确保保真度和功能损失最小。神经工程系统设计项目大大提高了神经技术的研究能力,需要多学科的融合,包括神经科学、合成生物学、低功率电子学、光子学、医疗器械包装和制造、系统工程和临床测试等多种学科^[5]。

2017年,DARPA宣布将在4年内对NESD项目投资达6000万美元,支持布朗大学、哥伦比亚大学、法国视觉与听觉基金会、耶鲁大学约翰·皮尔斯实验室、Parad-

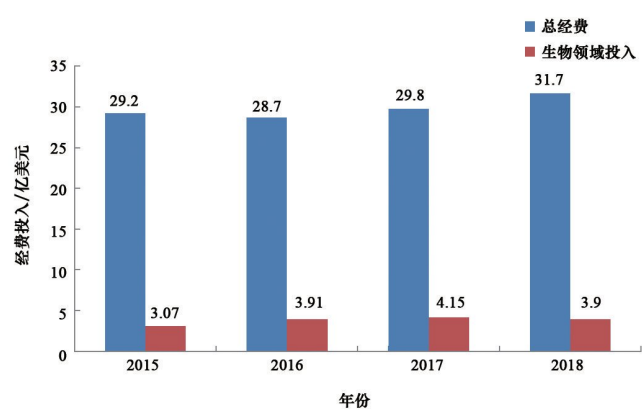


图1 DARPA近年来经费投入与生物技术领域投入情况比较
Fig. 1 The fund input in the biotechnology field compared with the total input

romics公司、加州大学伯克利分校6支研究团队开展该项目研究。布朗大学专攻解码语言神经的处理系统,注重知觉层面的语音与发声,团队设想的接口由植入大脑皮层的10万个亚毫米大小的无缆网络组成,像柔性电子贴片一样穿戴或植入的独立射频单元,负责转码和处理神经与数字信号。哥伦比亚大学团队将研究视觉领域,旨在研发连接视觉中枢的非穿透生物界面,试图在大脑皮质上建造一个包含集成电子阵列的独立柔性互补式金属氧化物膜电阻半导体(CMOS)集成电路,由头部佩戴的中继站收发器驱动植入体内的装置并与之保持无线通信。法国视觉与听觉基金会将利用光遗传学技术,以植入电子设备与微型发光二极管(LED)光学技术系统作技术支撑,实现人造视网膜与视觉中枢神经元之间的通信。耶鲁大学约翰·皮尔斯实验室将研发研发接口系统。Paradromics公司团队,将利用穿透性微型电线电极研制高数据速率的大脑皮质接口,实现神经元的刺激和高分辨率记录。加州大学伯克利分校团队,旨在研发新型“光场”全息显微镜,可探测和调制大脑皮质层中近100万个神经元的活动。团队还将研发量化编码模型,预测神经元对于外部视觉刺激和触觉刺激的反应,之后再利用预测结果构建引起视觉或躯体感觉皮层的感官知觉的“光刺激模型”^[6]。

1.2 大脑调制解调器植入项目(Stentrode)将逐步实现人机一体化

DARPA于2016年2月8日宣布已经成功开展相关试验,在动物体内导入一种微型传感器,通过血管植入大脑并记录下神经活动。这种名为“stentrode”的电极

装置只有回形针大小,外形灵活可变。这种微型装置由澳大利亚墨尔本大学神经学家汤姆·奥克斯利和其团队开发,DARPA 投资 6200 万美元,帮助研究人员解决了开发大脑调制解调器过程中一个最麻烦的问题,即如何安全地把信号发射器植入使用者大脑。该装置作为一种高带宽的神经接口,可让人类大脑与外部电子设备实现数据信息交互。“Stentrode”装置包括传感器和一个微型信号发射器,已在绵羊身上测试。DARPA 希望通过人脑植入设备后可以直接与计算机交流,这对患有听觉及视觉障碍的人来说极其便利。而这一植入设备也为这些人提供了新的疗法,将听觉或视觉信息直接输入大脑,实现之后,人脑想执行某个操作,不需要通过肢体动作,而是通过“脑机接口”技术,即可让外部设备读懂大脑神经信号,并将思维活动转换为指令信号,来实现人脑思维的操控^[7]。

DARPA 发言人表示项目并非用于军事,但一些专家认为,该设备具有多种军事应用的潜能,包括穿戴式机器人领域,以提高和恢复人类的工作效率。外骨骼技术也是美军加紧研制的一个人机融合的重要方向。未来如果这两种技术进行高效融合,那机械战士就有可能实现。

目前,美军正在发展一种电池作为动力的外骨骼,即轻型战术突击作战服(TALOS),以便提供免受敌方火力攻击的超级防护能力,提高使用者通信和视觉能力。该作战服是在美国特种作战司令部监督下研发。理论上,植入芯片技术将允许士兵更为高效地操纵作战服,在战斗中更高效地控制有装甲防护的外骨骼。TALOS 项目计划在 2018 年秋天交付第一代套装。

美国哈佛大学机械和生物医学工程教授康纳尔·沃尔什表示,该植入设备将会改变游戏规则,而未来这种可植入设备将会控制穿戴式机器人。此外,穿戴式机器人具有帮助中风患者恢复健康及增强士兵战斗力的潜力。但植入技术仍然有很长的路要走。在该装置投入使用之前,需要在神经系统科学、合成生物学、低功率电子技术、光子学以及医学装置制造等诸多领域实现突破^[8-9]。

1.3 靶向神经可塑性训练项目(TNT)将有效提升学习认知能力

靶向神经可塑性训练项目发布于 2016 年 4 月,目的是通过激活周围神经系统加强大脑的神经联系,促进学习认知技能训练的效率。由于身体周围神经的分

支网络神经元将器官、皮肤、肌肉紧密联系,并调节消化运动感觉,传输并反馈大脑和脊髓信号,因此通过刺激周围神经元将有效激活大脑的学习认知。DARPA 的研究目标包括阐明周边和中枢神经系统回路中可调节突触可塑性的大脑解剖和功能图,了解周边神经刺激对认知能力的影响和大脑活动的机制,优化非侵入性刺激神经系统而且没有副作用的方法。该项目将建立促进广泛认知技能学习训练的广泛平台,缩短培养外语专家、情报人员、密码分析人员等相关技能的时间,提高成人的认知学习效率(图 2)^[10]。

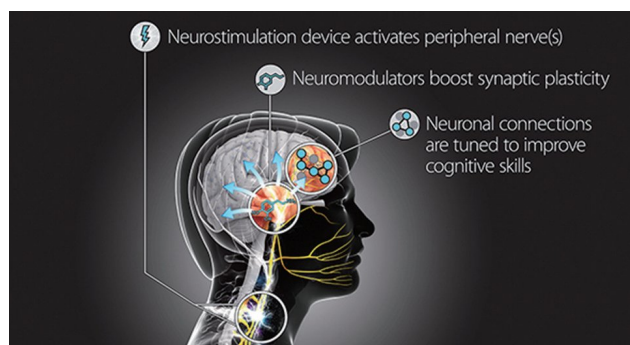


图2 DARPA TNT项目原理示意

Fig. 2 The principle diagram of DARPA TNT

与 DARPA 之前许多神经科学和脑科学的项目不一样,TNT项目的目标不仅在于功能恢复,而且包括能力的提高。DARPA 计划该项目从基础研究及工程应用研究分步开展研究。基础研究的目标是对一些问题有更清晰和更完整的理解,如神经刺激是如何影响突触可塑性的,大脑是如何控制认知技能学习过程的,如何安全地促进学习而不产生潜在的副作用等。工程应用方面的研究目标在于开发一个非侵入式装置,提供周围神经刺激,加强大脑负责认知功能区域的可塑性。该项目涉及认知神经科学、神经可塑性、电生理学、系统神经生理学、生物医学工程、人效能和计算建模等不同领域^[11]。

1.4 干预和共同预防及治疗(INTERCEPT)解决病毒变异难题

干预和共同预防及治疗项目发布于 2016 年 4 月,目标是开发和探索治疗性干扰颗粒(TIP)作为解决病毒变异的方法。TIP 是具有缺陷病毒基因组衍生的颗粒,其仅在病毒存在的情况下复制,通过竞争必需的病毒组分干扰病毒复制增殖。正如它们的亲代病毒一样,TIP 易于随时间突变,并且可以与突变病毒共同进

化,减轻病毒从治疗中逃逸。该计划将利用新型分子和遗传设计工具,通过高通量基因组技术和高级计算方法解决TIP的安全性、有效性、长期共同演化等普遍性问题^[12]。

INTERCEPT项目旨在探索和评估TIP作为治疗性或预防性方法的潜力,用以长期控制各类快速进化病毒。它重点关注4个关键技术挑战:1)安全性和有效性,即是否能够建立安全的TIP并竞争超越病原体,可短期控制感染;2)协同进化,即TIP是否可以与不断变化的病原体协同进化并保持同步,可长期控制感染;3)群体规模效应,即TIP是否可以与病原体共同传播,从而控制传染病在人群中的传播;4)普遍性,即TIP是否可以扩展到多种病毒,治疗与预防多种急慢性传染病。DARPA计划为INTERCEPT项目提供长达4年的研发资助,分为2个阶段,每个阶段为期2年:第1阶段需要对TIP的安全性、广谱效力、病原体协同进化进行初步的概念验证。研究将采用病毒感染的体外和体内模型,以及TIP-病原体-宿主动力学的数学模型;第2阶段将专注于TIP长期安全性和有效性的验证、长期协同进化研究、TIP协同传播动力学研究,并应用于群体规模的疾病控制^[13]。

1.5 普罗米修斯(Prometheus)项目将实现传染病早期快速诊断

普罗米修斯项目发布于2016年6月,旨在探索人体宿主感染呼吸道病原体的生物标志物分子,以早期发现与预测人体接触病原体后是否发生感染,研发病原体感染早期检测方法。目的是对宿主带有的能预测传染病传播潜能的分子生物学特征进行研究,最终目标是用少量的早期人体宿主生物标志物在感染或接触病原体24 h内预测被感染的情况。通过基于基因组学、蛋白质组学、代谢组学和表观基因组学的分子工具可以确定和量化接触病原体或发病后产生的生物标记物,以评估疫苗接种史、疾病进展和环境暴露等因素。该项目主要包括2个主要技术领域:一是发现宿主分子靶标,二是研究预测算法^[14]。

1.6 流行病预防平台(P3)将研发出可快速定制的RNA疫苗

流行病预防平台(P3)项目发布于2017年2月,旨在开发一个综合技术平台,使公共卫生官员能够在60天内阻止任何病毒性疾病的蔓延,避免使其发展为大规模流行状态。目前最先进的医疗措施(如疫苗)

通常需要花费数月甚至数年进行开发、生产、分发和管理,与之相比,P3平台可将响应时间缩短到几周。该计划的目标是彻底改变爆发一响应能力,实现有效的DNA和RNA编码医疗措施的快速发现、生产、测试和分发。DARPA在近期实施的“支持预防和治疗自主诊断”(ADEPT)计划下开创的这一基础技术,试图在3个技术领域寻求突破:1)新的病毒生长方法;2)快速识别和培养保护抗体,增加其有效性技术;3)将核酸构建体递送到患者中,对目标抗体进行编码并产生保护响应的新技术,并实现相关技术与平台的集成,支持编码基因结构在应对大规模流行威胁中的快速、可扩展使用(图3)^[15]。

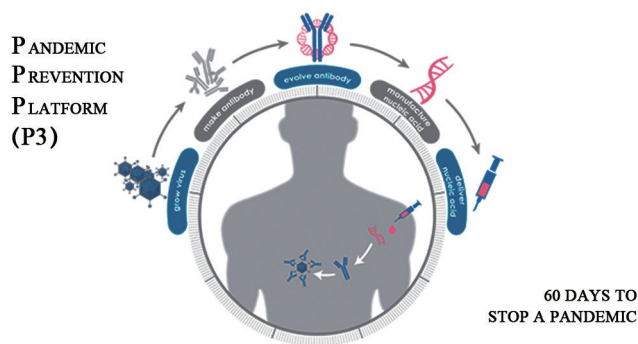


图3 DARPA P3项目原理示意

Fig. 3 The principle diagram of DARPA P3

1.7 安全基因(Safe Genes)项目应对基因编辑潜在威胁

2016年9月,DARPA发布安全基因项目,目标是在发展先进基因组编辑技术提升生物能力的同时保障生物安全,在新的生物技术形成初期建立生物安全研究,开展一系列应对人为基因威胁,创建应急基因编辑技术潜在性、可能性和薄弱方面的知识体系。项目包含3个技术领域,分别为基因组编辑活性控制、应对和预防措施及基因修复。基因组编辑活性控制研究,需要对设计、开发遗传电路和基因组编辑机制进行研究,以实现在生命系统中对基因组编辑行为的空间、时间和可逆性进行控制。应对和预防措施方面,需要开发防止或限制基因编辑活性的小分子或分子策略。基因修复策略研究,需要从广泛复杂的人群和环境背景中消除不想要的基因,以恢复生物系统功能和遗传基线状态。该项目为期4年,共分为2期:一期将建立基本的工具并在体外和体内对技术领域进行概念验证;二期

研究重点是,在生物活体内原位验证所选工具和方法的有效性、安全性、特殊性和稳定性(图4)^[16]。

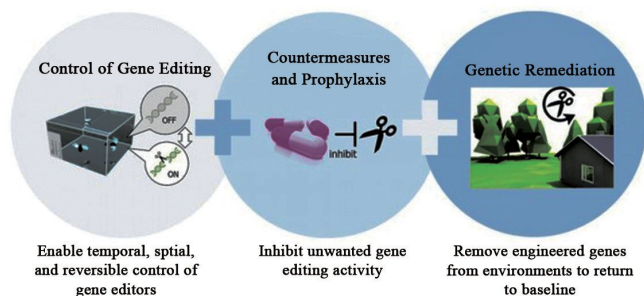


图4 DARPA安全基因项目原理示意

Fig. 4 The principle diagram of the Safe Gene Project of DARPA

2017年7月,DARPA与麻省理工学院-哈佛大学博德研究所(Broad Institute)、哈佛医学院、马萨诸塞州总医院、麻省理工学院、北卡罗来纳州立大学、加州大学伯克利分校和加州大学河滨分校等7个研究团队签署总额为6500万美元的研发合同。

1.8 昆虫盟友(Insect Allies)项目将增强植物抗病性

农业粮食生产是促进国防准备、社会稳定和经济活力的基本人类活动,但同时受到病毒、害虫、真菌、除草剂、干旱、污染、盐分、水灾和霜冻等自然威胁和人为威胁的危害。虽然传统的农业威胁响应(如作物轮作、选择性繁殖、杀虫剂、纵火游耕和检疫)可提供一定的保护,但不适合应对突发威胁,而且不适合保护成熟植物。昆虫盟友项目旨在利用自然和有效的两步递送系统,将修改的基因转移至昆虫载体及其传播的植物病毒,把某些害虫转化为“盟友”,提供传统响应的替代方案,在单个生长季节内使用靶向基因治疗保护成熟植物。

该项目提出该计划包括3个技术领域:病毒操纵、昆虫载体优化及针对成熟植物的选择性基因治疗。目前,保护植物的现有最有效方法之一,即选择性育种抗病性,通常需要5~7年的工作来确定相关的保护性基因,再需要10年或更长时间才能在植物种群中繁殖所需的性状,昆虫盟友项目成功后将完成单个季节内实现所需性状表达的效果。除了保护作物外,该项目拟开展的基础知识和通用工具研究也可以支持未来的农业创新。该项目强调生物安全性,所有工作都将在封闭的实验室、温室或其他安全设施内进行。

1.9 生物控制项目将建立多级生物系统控制平台

生物控制(biological control)项目发布于2016年2月,旨在通过由生物部件制成的嵌入式控制器对生物系统行为进行编程,建立从纳米到厘米、从秒到数周、从生物分子到生物群体的生物系统层级控制能力。

项目将利用在生物系统中广泛存在的调控机制,通过组合这些机制来实现工程生物系统的控制,包括小分子(例如转录因子和核糖开关)、具有多个亚基的大蛋白质(如分子发动机和跨膜受体)等。所得到的生物控制工具方法和控制策略将广泛适用于各种生物系统,从无细胞系统和传统的实验室微生物到合成的有机体系统和动物模型,同时还将进行生物控制的预测模型理论研究。研究包括生物控制工具、生物控制检测平台、理论与模型3个方面,包括开发不同级别的闭环生物控制工具、多尺度控制策略、有效预测和设计的理论和模型,以及评估系统级行为控制的测试台等。该项目将影响到多种生物系统的控制,为工程生物学创造新的发展前景。

1.10 工程活体材料(ELM)开发将具有生命力的建筑材料

工程活体材料项目发布于2016年8月,目标是开发活体材料,将传统建筑材料的结构性能与生命体快速生长、自我修复和适应环境的属性相结合。活体材料是一个全新的领域,利用工程生物学来解决建筑学建设和维护难题,创造动态响应周围环境的智能建筑。项目目标是开发活体材料结构特征工程化的蜂窝系统工具与方法,并通过生产可以繁殖自组织和自愈合的生物材料来验证。ELM希望能够将木材、混凝土等惰性建筑材料的功能与3D打印组织和生物支架的生长能力相融合。ELM的技术路径一是寻求递送由支持活细胞生长的惰性结构支架组成的杂交材料,二是发现材料的基本工程原理,将结构特征遗传编程到生物系统中,以开发能够实现指定和可调模式和形状的多细胞系统。

2 未来研究方向

2017年2月,美国国防科学委员会成立生物学特别工作组,目标是探索和阐明现代、新兴生物科学进展的机遇和潜在风险,增强美国国家安全和防御能力。重点关注现代生物科学发展最迅速的领域,特别是有可

能为国防创新提供新机遇的基础技术领域,或被对手掌握威胁美国国家安全的技术领域。2017年4月,DARPA生物技术办公室发布方案征集公告,寻求生物技术研究创新方案,旨在利用神经科学、心理学、认知科学等相关学科的最新进展,先一步将重点开展人效能优化、人机系统结合、生物系统行为设计和控制、生物样品采集分析处理平台、极端环境条件作业技术、物体聚集和互动行为的因素和原则、生态系统避灾战略、农业生态系统新技术、非人类生物体探索、生物安全、全球粮食和水供应对策,以及突发传染病应对策略等领域的研究和技术开发等。

3 结论

2014年DARPA成立生物技术办公室以来,将原来分散于其他部门管理的生物与医学技术进行统一管理,显示DARPA加大了对生物技术领域的管理力度,也凸显出生物技术在国防科技中的战略重要性,但DARPA有些生物技术相关项目并未完全转入生物技术办公室,像生物组装、大脑模型、生物材料等众多生物交叉领域的研究项目仍分散在其他办公室。

从经费投入和目前进展来看,DARPA近年来在生物领域投入稳定,逐步在脑机接口、生物安全、合成生物学等领域取得较为系统的成果,并着眼影响国家和军事安全的重大生物威胁,部署一些前沿性、颠覆性技术,如基因驱动技术(自我永久基因编辑系统,即通过有性繁殖的群体中的基因变异)等。

中国军事科研部署中也需要借鉴DARPA管理机制和投入方式,在军民融合和国防创新环境下,充分利用国家实验室、国防实验室与地方企业的技术优势,聚焦直接影响国防和军事安全的相关领域和前沿技术,凝练战略发展方向,构建战略研究体系,打破学术壁垒,集中经费投入,采用灵活多样的挑战赛和项目组织形式,培养创新型、跨学科的人才方阵,整体推进军用生物交叉技术的研究。

参考文献(References)

- [1] DARPA launches biological technologies office (BTO)[EB/OL]. (2014-04-01) [2017-11-10]. <https://globalbiodefense.com/2014/04/01/darpa-launches-biological-technologies-office-bto/>.
- [2] US Department of Defense: Fiscal year 2018 budget request [EB/OL]. (2017-05-30) [2017-11-10]. http://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2018/fy2018_Budget_Request.pdf.
- [3] Steinberg E E, Christoffel D J, Deisseroth K, et al. Illuminating circuitry relevant to psychiatric disorders with optogenetics[J]. *Current Opinion in Neurobiology*, 2015, 30: 9-16.
- [4] Miranda R A, Casebeer W D, Hein A M, et al. DARPA-funded efforts in the development of novel brain-computer interface technologies[J]. *Journal of Neuroscience Methods*, 2015, 244: 52-67.
- [5] United States Department of Defense FY17 budget request [EB/OL]. (2016-02-30) [2017-11-10]. http://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2017/FY2017_Budget_Request_Overview_Book.pdf.
- [6] Strategic Plan, Defense Advanced Research Projects Agency [EB/OL]. (2016-02-30) [2017-11-10]. <https://www.darpa.mil/about-us/budget>.
- [7] Department of Defense Fiscal Year (FY) 2017, Resident's budget submission[EB/OL]. (2016-02-09) [2017-11-10]. <https://www.darpa.mil/attachments/DARPAFY17PresidentsBudgetRequest.pdf>.
- [8] Human performance modification: Review of worldwide research with a view to the future[R]. NW Washington, DC: National Research Council of the National Academies, 2015.
- [9] National Intelligence Council. Global trends 2030: Alternative worlds[M]. Holman Lounge: Office of the Director of National Intelligence, 2012.
- [10] Mike J. Walker. Hype cycle for emerging technologies[R/OL]. (2017-07-21) [2017-11-01]. <https://www.gartner.com/doc/3768572>.
- [11] DARPA BAA 16 24: Neuroplasticity training (TNT) BAA[EB/OL]. (2014-04-01) [2017-11-10]. <https://www.darpa.mil/attachments/DARPA-BAA-16-24FAQV1.pdf>.
- [12] DARPA INTERCEPT program for biodefense countermeasures [EB/OL]. (2016-04-11) [2017-11-10]. <https://globalbiodefense.com/2016/04/11/darpa-bto-intercept-therapeutic-platform>.
- [12] DARPA awards research contract for co-evolving countermeasures for biothreats[EB/OL]. (2017-04-18) [2017-11-10]. <https://globalbiodefense.com/2017/04/18/dstl-darpa-intercept-evolving-countermeasures-bioterrorism>.
- [14] Prometheus BAA: DARPA-BAA-16-42[EB/OL]. (2016-06-15) [2017-11-10]. <https://www.fbo.gov/utis/view?id=e0dae52f29a96a52c1371681c925ac30>.
- [15] DARPA Pandemic Prevention Platform (P3) proposers day events[EB/OL]. (2017-02-07) [2017-11-10]. <https://globalbiodefense.com/2017/02/07/darpa-pandemic-prevention-platform-p3-proposers-day-events>.
- [16] Setting a safe course for gene editing research[EB/OL]. (2016-09-07) [2017-11-10]. <https://www.darpa.mil/news-events/2016-09-07>.

Analysis of the deployment of biotechnology projects of the Defense Advanced Research Projects Agency

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Abstract Since 2014 when the U.S. Defense Advanced Research Projects Agency announced the establishment of the Office of Biotechnology (BTO), focusing on the restoration and the enhancement of military capability, the engineering application of biological system and the large-scale application of biological complexity, the number of research projects has increased from 23 to 31. The investment becomes more rational, and the research more focused. On the basis of the literature research, the expert consultation, the comprehensive analysis, the comprehensive inductive reasoning and other methods, this paper analyzes the deployment of biotechnology projects in the years of 2016 and 2017, reviews their characteristics, including the focus on the field of brain machine interfaces, the rapid diagnostic techniques, the countermeasures of biosafety protection, and the biological systems engineering.

Keywords DARPA; biotechnology projects; deployment ●



(责任编辑 王志敏)

Targeted Neuroplasticity Training (TNT)

Doug Weber, Ph.D.

Program Manager, Biological Technologies Office (BTO)

8 April 2016





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Cognitive-skill training is vital part of fulfilling national security mission

TNT Goal: Faster, more effective cognitive training for a variety of DoD applications

DoD applications of interest to the TNT program include, but are not limited to:



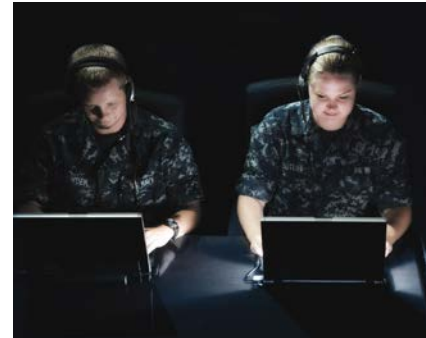
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Tactical Operations Center
(TOC)



© Staff Sgt Justin Weaver

Foreign Language



© US Navy

Cryptography



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Intelligence



TNT – enhancing cognitive skill learning

Vision: enhancing cognitive skill learning in healthy adults by using noninvasive peripheral neurostimulation to promote synaptic plasticity in the brain

Cognitive Training Protocols

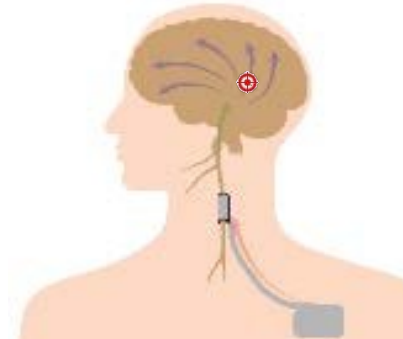


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Engage task-specific brain regions

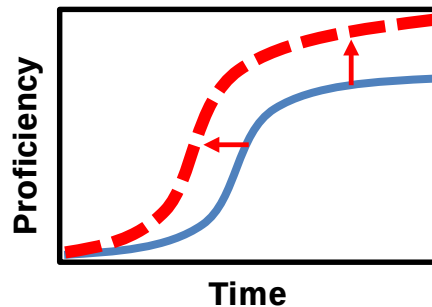


Peripheral Nerve Stimulation



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Engage neuromodulatory circuitry

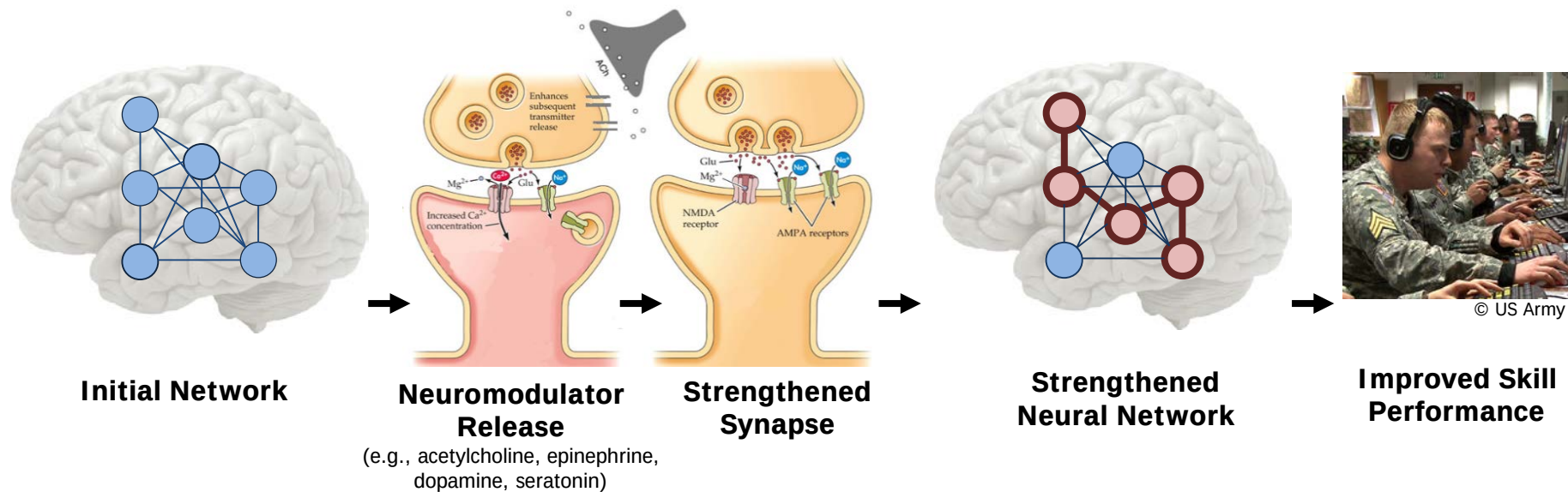


Result:

Train personnel **faster** & with **superior** cognitive abilities



Skill learning and the brain

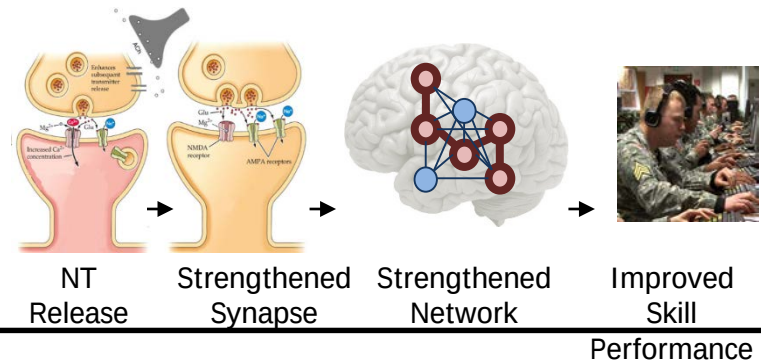




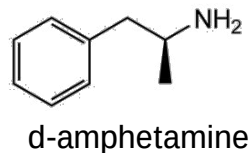
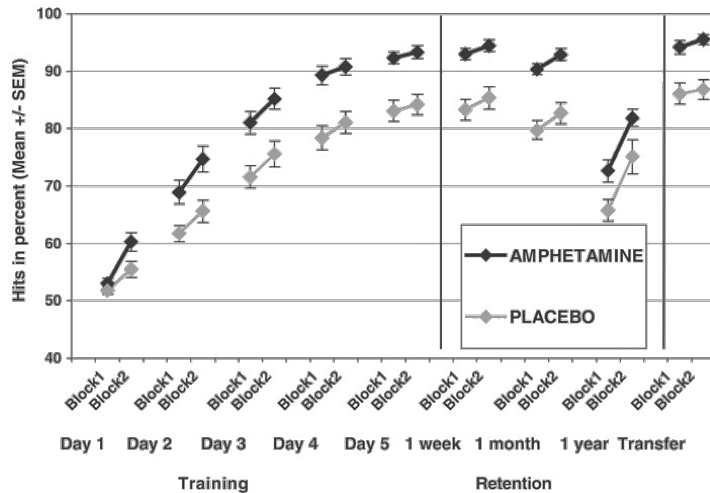
Skill learning and the brain

Pharmaceuticals

Enhances Learning?	Specific?	Invasive?	Side Effects?
Mixed - Some agents promote learning under specific circumstances	No	No	Yes, such as addiction, cardiac, and respiratory effects

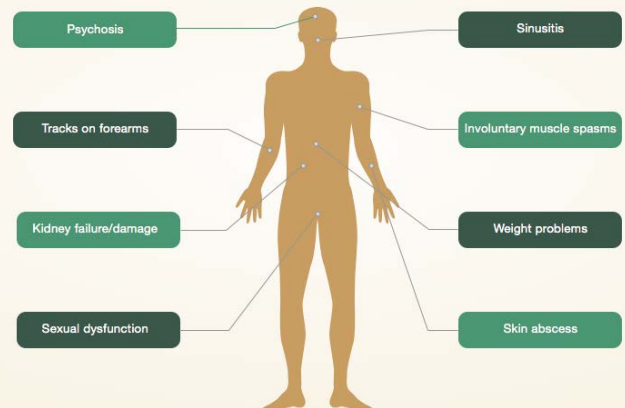


Language transfer from visual to spoken material



Amphetamine Long-Term Effects

Abusing amphetamines over a long period of time can cause many mental and physical problems.



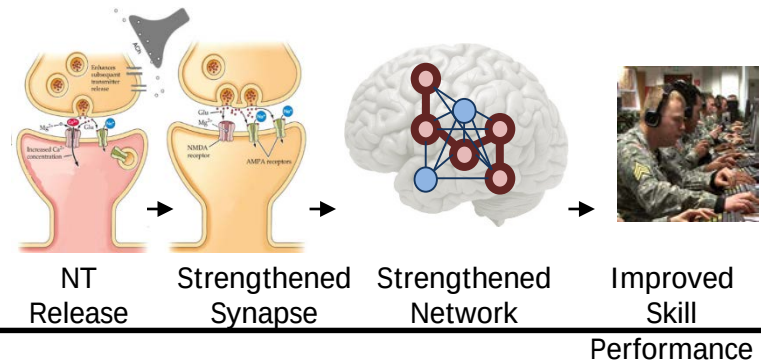
Breitenstein et al., 2004



Skill learning and the brain

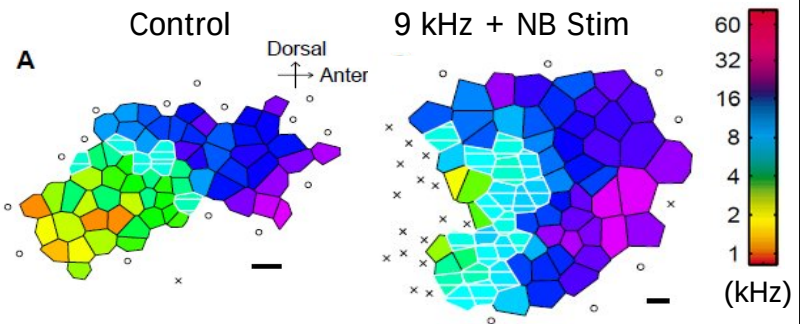
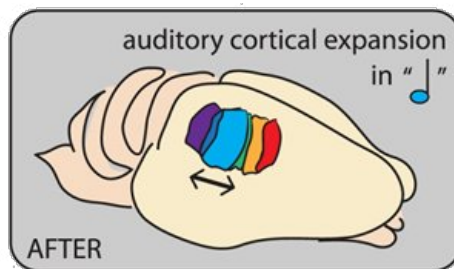
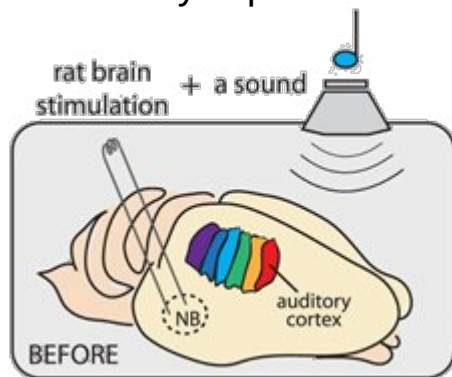
Deep Brain Stimulation

Enhances Learning?	Specific?	Invasive?	Side Effects?
Yes	Specificity depends on device	Requires implantation into brain	Surgical complications, off-target effects



Paired Brain Stimulation and Sensory Exposure:

Increased representation of paired tone in auditory cortex:



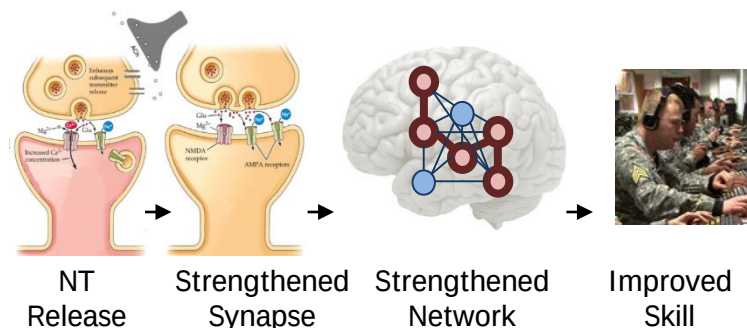
Kilgard et. Al., 1998



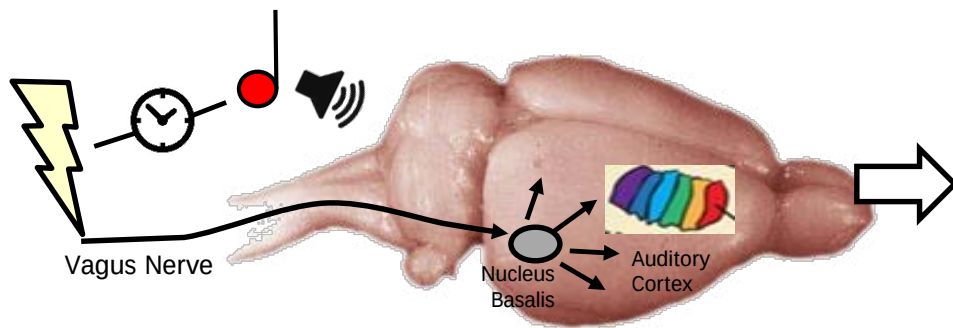
Skill learning and the brain

Invasive PNS Stimulation

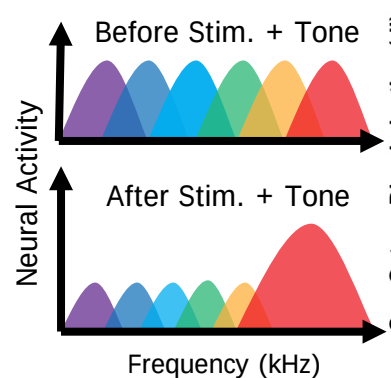
Enhances Learning?	Specific?	Invasive?	Side Effects?
Yes	Yes	Yes	Yes, minor



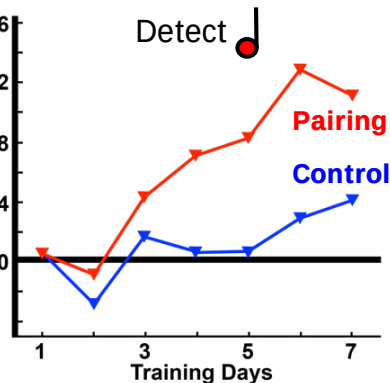
Paired Nerve Stimulation and Sensory Exposure:



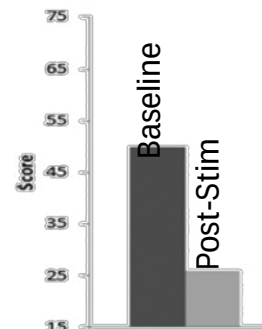
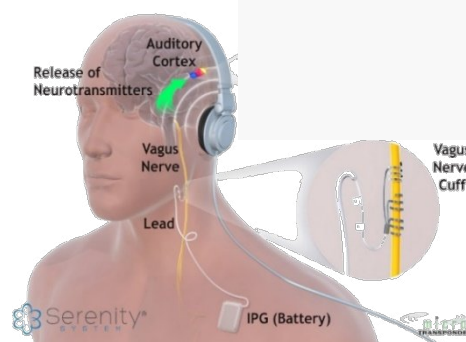
Neural Changes:



Behavioral Improvement:



Tinnitus Rehab in Humans:

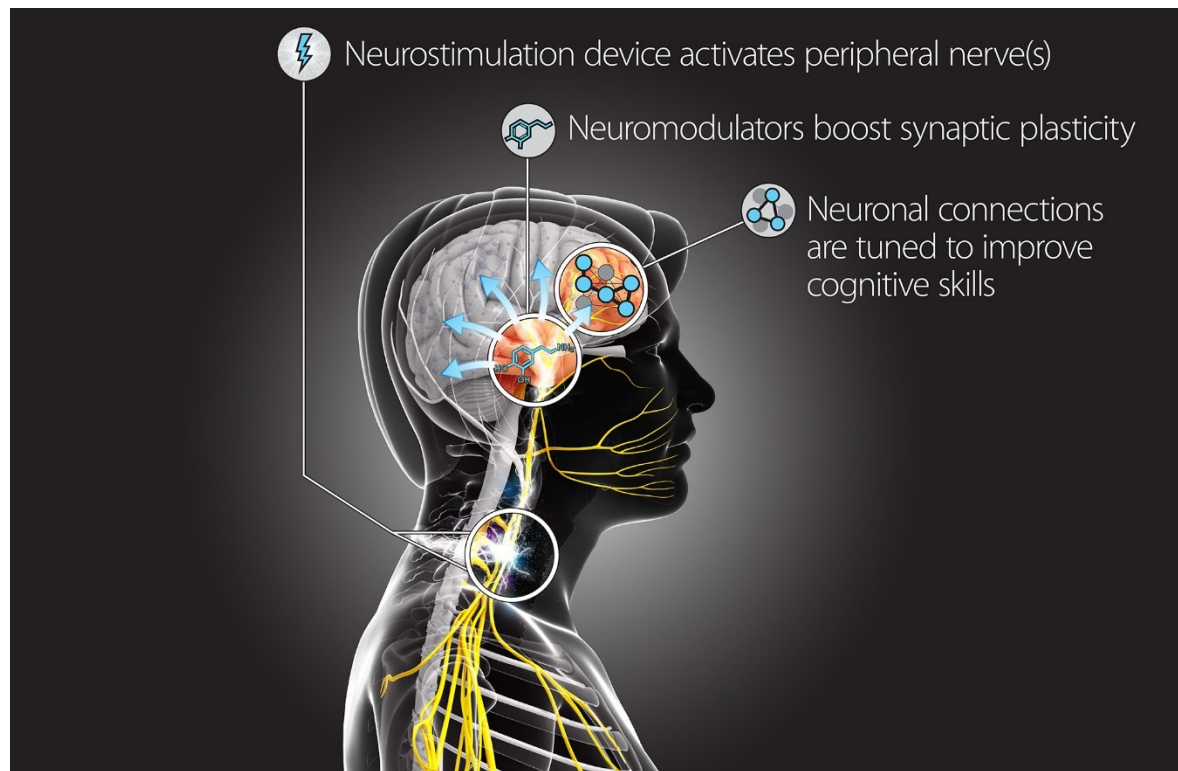
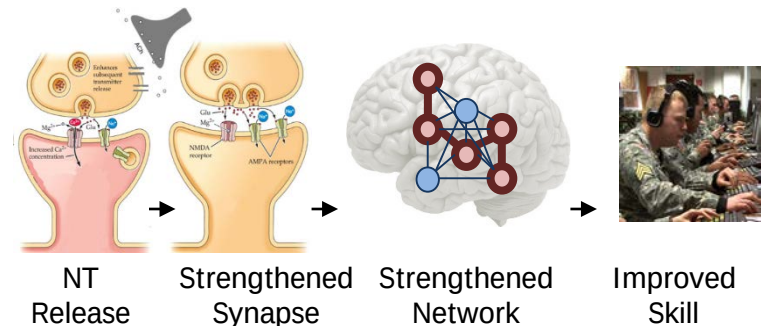




Skill learning and the brain

Training + Non-Invasive PNS Stimulation

Enhances Learning?	Specific?	Invasive?	Side Effects?
Yes	Yes	No	No





General Objectives

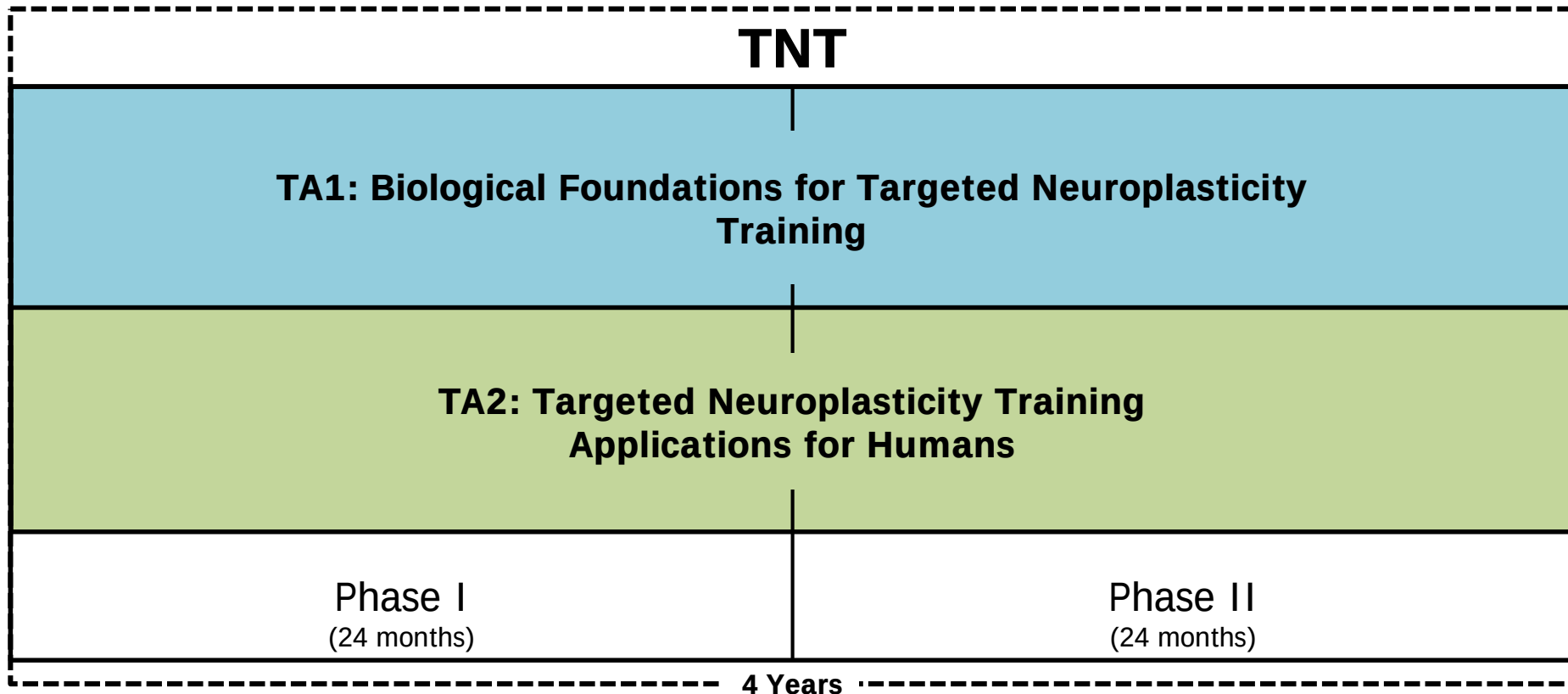
- 1) Elucidate the anatomical and functional map(s) of the peripheral and central nervous system circuitry that regulates synaptic plasticity in the brain
- 2) Demonstrate effects of peripheral neurostimulation on cognitive skills and the brain activity supporting those skills
- 3) Optimize noninvasive stimulation methods and training protocols for long-term retention without negative side effects

By the end of the 4-year TNT program:

Demonstrate that targeted neuroplasticity training methods yield at least a
30 % improvement in learning rate and/or skill performance
with minimal negative side effects



Program Structure



TNT goal: Demonstrate that targeted neuroplasticity training methods yield at least a **30 % improvement in learning rate and/or skill performance** with minimal negative side effects

End-of-Phase goals set by DARPA (see BAA and following slides)
Intermediate milestones set by performer and should be identified within proposal



TA1: Biological Foundations for Targeted Neuroplasticity Training

TA1 Primary objective: perform hypothesis-driven research to measure and demonstrate effects of peripheral neurostimulation in promoting plasticity, and assess quantitative changes in neurophysiology and behavior

Phase I Goals	
Research Objectives	Milestones and Deliverables
Demonstrate that peripheral neurostimulation promotes synaptic plasticity by measuring changes in neural activity and neurochemicals in brain.	Provide data validating proposed hypotheses regarding functional and anatomical map(s) of circuitry between peripheral nerve and CNS structures. Input/output response profiles for peripheral neurostimulation and plasticity modulation in CNS.
Demonstrate acute effects of targeted neuroplasticity training on brain neurophysiology and learning rate and/or skill performance at least 15% greater than control.	Provide data demonstrating quantified changes in task performance (e.g., accuracy, speed) and neural network physiology (e.g., neural tuning functions and functional connectivity) with training.
Test for off-target effects of peripheral neurostimulation and training.	Provide stimulation parameter map for identified side effects.



TA1: Biological Foundations for Targeted Neuroplasticity Training

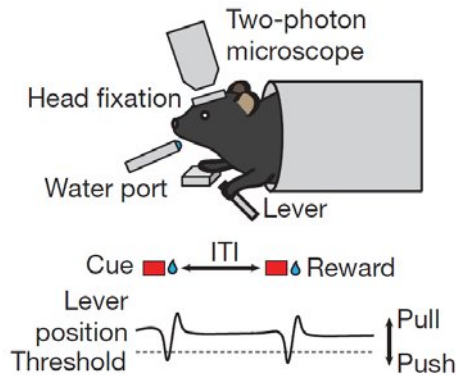
TA1 Primary objective: perform hypothesis-driven research to measure and demonstrate effects of peripheral neurostimulation in promoting plasticity, and assess quantitative changes in neurophysiology and behavior

Phase II Goals	
Research Objectives	Milestones and Deliverables
Demonstrate chronic effects of targeted neuroplasticity training on neurophysiology and learning rate and/or skill performance at least 30% greater than control, including measures of long-term retention of trained skills.	Provide data demonstrating quantified changes in task performance (e.g., accuracy, speed) and neural network physiology (e.g., neural tuning functions and functional connectivity) over training periods that span days or weeks and retention evaluated >30 days after training.
Optimize stimulus protocols in animal models to minimize negative side effects.	A peripheral neurostimulation and training protocol that exhibits minimal side effects in animal models.

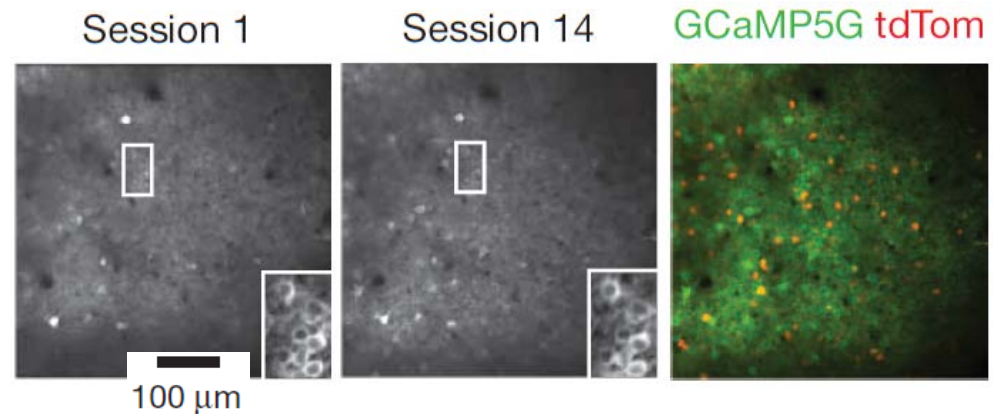


Large-scale neural recording and learning studies

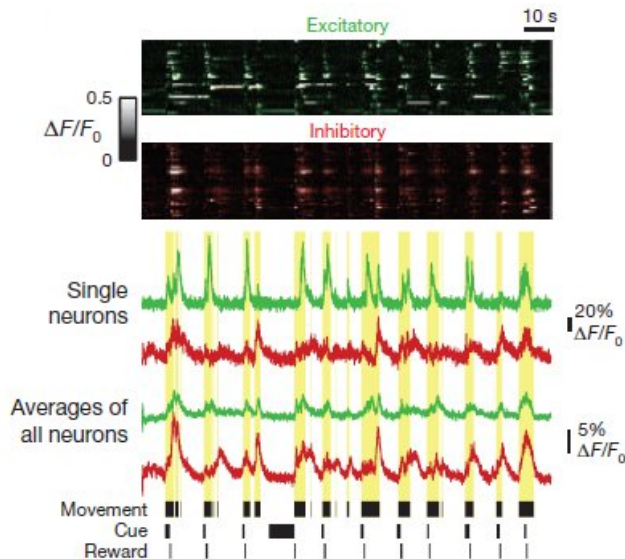
Motor learning task



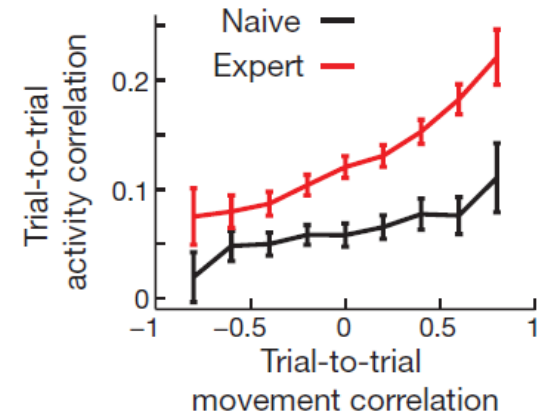
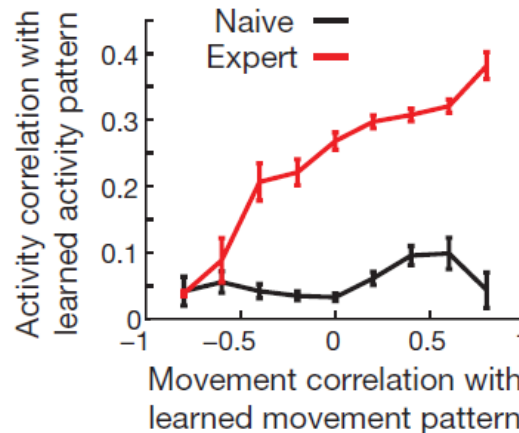
Calcium imaging of neurons in motor cortex



Analysis of neuronal activity



Coordinated evaluation of neuronal activity and task learning



Peters et. al., Nature 2014



TA2: Targeted Neuroplasticity Training Applications for Humans

TA2 Primary objective: Develop, demonstrate, and validate cognitive-skill training applications for humans that leverage noninvasive peripheral neurostimulation to promote synaptic plasticity.

Phase I Goals	
Research Objectives	Milestones and Deliverables
Identify mechanisms for modulating neuroplasticity in humans with noninvasive peripheral neurostimulation devices.	Provide data validating proposed hypotheses regarding specific peripheral nerve targets for stimulation and effects on synaptic plasticity, brain function, and learning rates.



TA2: Targeted Neuroplasticity Training Applications for Humans

TA2 Primary objective: Develop, demonstrate, and validate cognitive-skill training applications for humans that leverage noninvasive peripheral neurostimulation to promote synaptic plasticity.

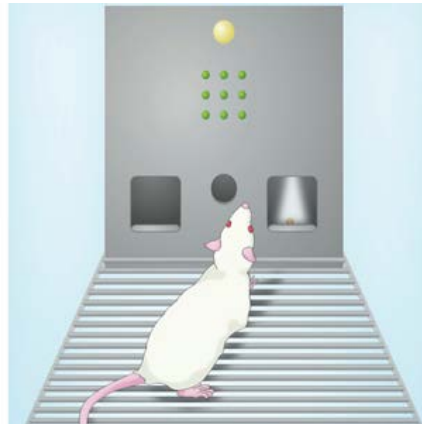
Phase II Goals	
Research Objectives	Milestones and Deliverables
Refine peripheral neurostimulation and training protocols to ensure easy and reliable operation with minimal negative side effects.	A peripheral neurostimulation device and training protocol with reliable indicators of target nerve engagement and empirical data demonstrating minimal side effects on physical and cognitive functions.
Evaluate benefits of targeted neuroplasticity training with goal of demonstrating learning rate and/or skill performance at least 30% above control.	Provide performance data from randomized, controlled study comparing learning rates and retention between targeted neuroplasticity training and unstimulated controls.



Program Structure

Performer responsibility:

Demonstrate that your approach reduces training time in a lab setting



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DARPA responsibility:

Find appropriate DoD partners to pursue implementation in the field



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Scope

	IN SCOPE	OUT OF SCOPE
Stimulation Approach	Technologies targeting the peripheral nervous system	Technologies targeting the central nervous system (including, but not limited to, tDCS, tACS, tRNS, TMS, DBS)
Targeted Skills	Perception, comprehension, decision making, motor control, and many others	Memory
Application space	DoD-relevant training in healthy adults (including, but not limited to, foreign language learning, TOC control, intelligence analysis, cryptography)	Rehabilitation and other clinical applications

Use of **NONINVASIVE** technologies is required.
Use of **INVASIVE** technologies for comparison is encouraged.

Use of **COTS technology** is expected. Development of novel devices is discouraged.



Proposals and Teaming

- Proposal Due Date: **June 2, 2016**
- Proposals must address TA1 and TA2 **in full**

Teaming

It is anticipated that teaming will be necessary to cover the wide range of animal and human tasking required in this program

Tips:

- 1) Listen to presenters during today's "intro blitz" sessions, where attendees will briefly present their expertise and capabilities
- 2) Utilize the TNT teaming website: <https://team.sainc.com/TNT/home.aspx>.
- 3) Reach out to colleagues and collaborators



BAA Inbox and FAQ

- Direct **ALL** questions and communication to the BAA Inbox
 - DARPA-BAA-16-24@darpa.mil
 - Dr. Weber, any member of his team, or any member of the scientific review panel will not **directly communicate** with a potential proposer regarding BAA-16-24; all communication will be conducted through the BAA Inbox
 - Dr. Weber and the BAA Inbox cannot provide feedback or guidance on any aspect of your proposal, they can only clarify the content of BAA-16-24
- BAA Inbox FAQ
 - DARPA will post a consolidated FAQs on a regular basis
 - To access the posting go to:
 - <https://www.fbo.gov/spg/ODA/DARPA/CMO/DARPA-BAA-16-26/listing.html>
 - Submit your question(s) by E-mail to DARPA-BAA-16-24@darpa.mil at least 15 days before the proposal submission deadline



Advice

- Read the BAA, carefully – and respond accordingly.
 - Some instructions are specific – “required” and “must”
 - Most of the instructions are non-specific – you decide on what is the best possible science to support the objectives of the program
 - Be honest about risks and demonstrate thoughtful consideration for how to mitigate those risks.
- Ask for clarification as needed. FAQs will be updated regularly.
- Take advantage of today’s opportunities to meet potential teammates and ask questions

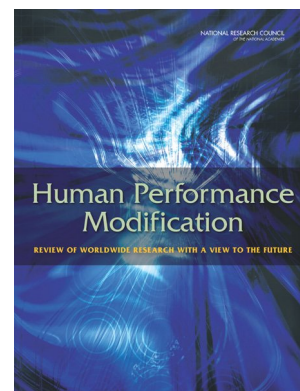


www.darpa.mil

Human Performance Modification: Review of Worldwide Research with a View to the Future

Division on Engineering and Physical Sciences · Division of Behavioral and Social Sciences and Education · November 2012

There is a long history of performance modification in humans. Techniques have ranged from the ingestion of substances found in nature, such as caffeine, to training regimens, electronic stimulation, and ergonomic system design—these practices continue today with products such as energy drinks and brain-training video games. Advances in medicine, biology, electronics, and computation have enabled an increasingly sophisticated ability to modify the human body. The resulting innovations will undoubtedly have applications for military forces as well. This National Research Council (NRC) report explores the development of technologies that expand and change physical and cognitive performance in humans with a specific focus on implications for the U.S. Armed forces.



Background and Introduction

It is clear that human performance modification (HPM)—both for enhancement and degradation of capabilities—is a subject of active research in all the technologically developed countries and regions of the world. Such innovations will undoubtedly be adopted by military forces with potential consequences for both sides of the battle lines. For example, research in injury recovery and physical performance enhancement, now mostly in the sports-research sector, has clear applications for military force development and maintenance. At the same time, some advances may be developed initially for military applications but likely will not remain exclusively in that sphere due to globalization and internationalization of the commercial research base.

Human Cognitive Modification as a Computational Problem

Human perception and performance can be modified (augmented) by the use of technological systems, known as artifacts, that complement and enhance human cognitive abilities. A cognitive artifact does not make a person smarter; instead, it is the combined human-artifact system that is smarter or more capable. As an example, a system that assists a battle-vehicle operator in maneuvering through rough terrain might record images with a camera, process the information by categorizing and locating objects, and alert the operator.

Computation for Human Performance Modification

While machines excel at precise, repetitive operations, humans are adept at tasks requiring flexibility and creativity and at responding to novel, unexpected situations. Unfortunately, many computational designs currently do not take advantage of human capabilities and instead force humans to operate by machine rules and logic. With better attention to the well-established principles of human-centered design and human-systems integration, there could be a significant enhancement in human cognitive capability with no need for new research or new applications.

Computation for Cognitive Enhancement

Augmented reality has great potential to improve command choices and decision making and to enhance training and performance of distributed teams. The primary limitations include power demands and architecture design that do not currently support complex cognitive processing. Although advances in data storage and hardware design will improve this situation, computers may need to become more brain-like to meet the requirements of augmented reality. Reconfigurable computing offers one approach to much more energy-efficient, brain-like computers capable of self-learning and adjusting to tasks and requirements without having to be programmed. Although strong research in cognitive computing is performed worldwide, the United States currently has a competitive advantage in augmented cognition technology because it leads in the development of human-centered software.

Human Performance Modification as a Biological Problem

There are two technologies affecting human biological systems that will have an impact in the next 10-15 years: tissue engineering and mechanisms for addressing fatigue.

Tissue Engineering

Tissue engineering can be defined as the use of cells, engineering, materials, and suitable biochemical and physiochemical factors to improve or replace biological functions. There have been three approaches to tissue engineering: the conductive approach, using a material to provide the structural framework for cell infiltration; the inductive approach, using soluble materials to promote cell infiltration; and the cell-replacement approach, providing either an allograft from a donor or an autologous graft from the patient to repair a tissue. Tissue-engineering methods are focused on clinical repair, and current methods are unable to surpass the functioning of healthy tissue.

Fatigue: Judgment and Decision Making

Physical fatigue manifests itself in deteriorated dexterity, reduced eye-hand coordination, tremors, discomfort, and loss of strength and endurance. The primary contributors to work-related fatigue are long duty hours, inadequate sleep, and disruptions to circadian rhythms that affect alertness and cognitive performance. New technologies for detecting and managing fatigue range from timed use of pharmacologic agents, such as modafinil, to highly precise light treatment devices.

Various technologies may affect the functional effectiveness of units that operate in extreme situations, such as long shifts, rotating shifts, and quick deployments across many time zones. In the next 5-10 years, top-down fatigue risk management systems will become commonplace in 24/7 operations as will the practice of removing sleep debt before critical operations.

Pre-travel adjustment of circadian rhythms will also be routine, and on-duty napping during 24/7 and nighttime operations will become an accepted practice.

The European Union is the leader in the field of fatigue research, with the United States, Australia, and Japan contributing extensively as well. Shift work in railroad operations—similar to military operations with 24-hour demands that encourage irregular schedules—has been studied extensively in Europe and Japan. Only recently has the United States begun to fund similar research to better understand the effects of irregularly scheduled work.

Human Performance Modification as a Function of Brain-Computer Interfaces

Brain-computer interfaces (BCIs) allow direct communication of neural signals with an external device—research explores the ability to detect, translate, and direct neural activity. Currently, effective BCIs are limited by incomplete identification of brain regions activated during specific processes.

Recently, electroencephalogram (EEG) spectra, which were obtained using neural probes implanted into a subject's brain, have been successfully reconstructed as sounds heard by the subject. Future research will seek to extend this capability to analyze EEG spectra of thoughts and convert them to speech; this is an exciting advance that could lead to individuals regaining the ability to speak. Especially intriguing for HPM is the use of nanotechnology for biointerfaces—materials, smaller than cells, that could possibly interact directly with the body on a biological level.

Non-U.S. entities are more active in such research on cognitive function. Despite a great deal of progress, however, it seems unlikely that human performance can be significantly enhanced via BCIs in the near term.

Committee on Assessing Foreign Technology Development in Human Performance Modification: **Hendrick W. Ruck**, Chair, Human Performance Consulting Group, LLC; **Julie J.C.H. Ryan**, Vice Chair, George Washington University; **Alice M. Agogino**, University of California, Berkeley; **Debra Auguste**, Harvard University; **Steven G. Boxer**, Stanford University; **Christopher C. Green**, Wayne State University; **Hendrik F. Hamann**, IBM Research; **James C. Miller**, Miller Ergonomics; **Joanna Mirecki Millunchick**, University of Michigan; **Donald Norman**, Nielsen Norman Group; **Laurie Zoloth**, Northwestern University

Staff: **Daniel E.J. Talmage, Jr.**, Study Director; **Cherie Chauvin**, Senior Program Officer; **Gregory Eyring**, Senior Program Officer; **Sarah Capote**, Research Associate; **Zeida Patmon**, Program Associate

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Forecasting emerging technologies with deep learning and data augmentation: convergence emerging technologies vs non-convergence emerging technologies

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Abstract:

Forecasting emerging technologies can help governments and enterprises in various countries to grasp the key to success in a new round of technological competition. The emergence of emerging technologies has multiple patterns and the development of emerging technologies with different emerging patterns will have fundamentally different requirements for governments and enterprises. Technological innovation based on multi-field technology convergence which can create numerous opportunities for development has led to great attention. The current research to convergence emerging technologies forecasting is mainly network analysis, text mining and evolution path clustering. We can't achieve a full automation forecast process to utilize these unsupervised methods, due to a large amount of domain knowledge is required to analyze the characteristics of the convergence emerging technologies. Supervised learning can automatically obtain forecasting results that use the already trained model, however, which requires the selection of excellent features and a large amount of labeled data to train forecast model. In this paper, we transform the forecasting question of emerging technologies into a multi-classification supervised machine learning question and propose an approach that forecasting convergence emerging technologies, non-convergence emerging technologies with deep learning and data augmentation. Our evaluation reveals that our proposed approach can forecast the convergence emerging technologies and non-convergence emerging technologies 1 year before they emerge with high precision.

Keywords: Forecasting emerging technologies, Data augmentation, Deep learning

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1 Introduction

With its characteristics of “creative revolution”, emerging technologies have created opportunities for latecomers to achieve leaping development. Forecasting emerging technologies can help governments and enterprises in various countries to grasp the key to success in a new round of technological competition. The emergence of emerging technologies has multiple patterns and the development of emerging technologies with different emerging patterns will have fundamentally different requirements for governments and enterprises.

There are two emerging patterns for emerging technologies according to current research. On the one hand, it may arise from breakthrough innovations and create new technological paths. On the other hand, it may also result from the gradual innovation process and the convergence of two or more unrelated fields (Curran C S et al., 2010, Pennings J M et al., 2000, Stieglitz N et al., 2004). Among them, technological

innovation based on multi-field technology convergence has brought about tremendous changes in society and economy, which prompts changes in the existing market structure and competition rules as well as creates numerous development opportunities.

The current research to convergence emerging technologies forecasting is mainly network analysis, text mining and evolution path clustering. We can't achieve a full automation forecast process to utilize these unsupervised methods due to a large amount of domain knowledge required to analyse the characteristics of the emerging technologies in different patterns. Supervised learning can automatically obtain forecast results that use the already trained model, however, which requires the selection of excellent features and a large amount of labeled data. With the development of artificial intelligence technology, data augmentation can generate a large number of synthetic samples based on the distribution of real samples and deep learning can automatically combine features, which provide possibilities for overcoming above problems.

In this paper, we transform the forecasting question of emerging technologies into a multi-classification supervised machine learning question and propose an approach to forecast convergence emerging technologies (CET), non-convergence emerging technologies (NCET) with deep learning and data augmentation. First, we collect existing CET, NCET, non-emerging technologies (NET) and select multiple patent features for each technology as data samples. Second, the data samples are divided into training samples and testing samples and we use the generative adversarial network(GAN) to generate a large number of synthetic samples to amplify the scale of the training data. Finally, the deep neural network classifier(DNN) is trained through generated synthetic training samples and tested through testing samples.

As the empirical analysis, we used patent data from Thomson Innovation to evaluate the proposed approach. It reveals that our approach can forecast the CET and NCET 1 year before they emerge with high precision. This research provides an efficient and full automatic approach for forecasting emerging technologies. Further, this research is helpful to explore the potential application of artificial intelligence in forecasting emerging technologies.

2 Literature review

Forecasting emerging technologies is full of challenges. While technology forecasting in general has been acknowledged as an effective tool in order to anticipate and understand the potential direction, rate, and effects of technological change (Porter and Roper, 1991), these methods are not easy to forecasting emerging technologies.

We argue that the extent to which these methods are able to forecast emerging technologies, however, it is limited. For example, Qualitative studies were put forward to meet the demand of technology forecasting analysis in the early years. These included the Delphi method, scenario planning, interview analysis, etc. (Rowe and Wright, 2001; Daim et al., 2006; Drew, 2006; Shen et al., 2010; Cho et al., 2016, etc). There are many limitations to these methods, and the data sources for these

researches are subjective and expensive to collect. For the sake of the data reliability, many researchers conducted technology forecasting by combining qualitative studies with objective data. For example, Hsieh (2013) created a model that combined the Delphi method, fuzzy measurement, and a technology portfolio planning (TPP) model to analyze patents in large quantities before they were commercialized. However, due to the fact that these qualitative methods cost too much, their usage was limited for many years.

Other researchers promote technology roadmapping as an ideal approach for technology forecasting (Walsh, 2004; Jin et al., 2015; Lee et al., 2015; Li et al., 2015; Cho et al., 2016; Phaal et al., 2004, etc.). This method employs various data sources and is used to explore and communicate the evolution of markets, products and technologies, together with the linkages and discontinuities between various perspectives (Phaal et al., 2004). There are two kinds of technology development paths, namely continuous and discontinuous development. While the scope of technology forecasting is limited somewhat to 'posteriori trends', discontinuous technology evolves along totally different trajectories, thus technology road mapping will only provide implications to firms who are focusing on continuous or sustaining technology, and does not provide answers for firms who are faced with discontinuous or disruptive technology (Kim et al., 2016).

After that, bibliometric methods, especially those which are based on patents and academic papers are widely used to conduct quantitative technology forecasting. In bibliometric analysis, it is assumed that the number of patents or papers is related to the validity and quality of R&D activities (Narin, 1994). The researches of relationships between patents or papers are well organized, specifically, various methods are proposed including Bayesian models for patent clustering (Choi and Jun, 2014), keyword-based patent map (Jin et al., 2015; Lee et al., 2009) and topical analysis (Ma and Porter, 2015). The advantages of patent bibliometrics mainly lie in the reliability of data sources.

In recent years, the methods of text mining and machine learning began to appear in technology forecasting, and achieved a significant effect. A novel algorithm is proposed to automatically label data and then use the labeled data to train learners to forecast emerging technologies (Kyebambe M N et al., 2017). Dejing Kong (Kong D et al., 2017) proposed a novel method that combines data-mining with experts' knowledge to build patent-training examples, and then used a support vector machine-based classifier to single out all high-quality patents for each innovation attribute.

3 Methodology

3.1 Labeling CET, NCET, NET

In this paper, Gartner Emerging Technologies Hype Cycles (see www.gartner.com) is used to identify CET, NCET, NET. Gartner Emerging Technologies Hype Cycles was proposed by Gartner, the world's first information

technology research and analysis company, established in 1979. Gartner Emerging Technologies Hype Cycles, which began in 1995, aims to describe a specific stage of development of an emerging technology. Each year, Gartner selects a number of technologies that have significant potential or are highly hype-promoted from more than 2,000 technologies, resulting in an Emerging Technologies Hype Cycles. The curve has received extensive attention in various fields of society and is used to forecast and measure the development trend of technology. The latest released 2017 Gartner Emerging Technologies Hype Cycles is shown in Appendix A .

According to the characteristics of Gartner Emerging Technologies Hype Cycles, we propose a new method of labeling emerging technologies and non-emerging technologies. The technology that has entered Gartner Emerging Technologies Hype Cycles for the first time in a certain year (T year) is a emerging technology. The technology that has left Gartner's emerging technology maturity curve for some time in a given year is a non-emerging technology. Emerging technologies must show strong consistency and persistence over time to meet emerging standards. Before a technology can be labeled, it is important to obtain a relatively stable state, because many new technologies show some emerging technologies features, but they have not gained stability, leading them to not become emerging technologies in the end. Therefore, if a group of patents show features that can produce new technology categories in the near future, a group of patents will be labeled as emerging technologies. The technology that first entered Gartner Emerging Technologies Hype Cycles in a certain year (T year) is labeled as an emerging technology that is associated with the patent data corresponding to that technology in the T-1 year. Simply, this means that T-1 year of patent data tagged as emerging technology may create a new category or technology in the second year.

At present, the pattern of production is usually determined by experts in a focused manner. In this paper, convergence emerging technologies and non-convergence emerging technologies are labeled by reading relevant documents.

3.2 Datasets construction

According to the retrieved Gartner Emerging Technologies Hype Cycles from 2008 to 2017 and the method of 3.1.1, CET, NCET, NET are identified. Then, in the Thomson Innovation database (TI), the patent data of the corresponding technology is retrieved. The technology feature vector of each technology is calculated from the patent data, and is used as the original sample for model training and model testing.

3.2.1 Patent data collection

Thomson Innovation is the only global innovation platform that integrates patents, scientific literature and business and news information, and provides unique tools for analysis, cooperation, and early warning, which is oriented toward corporate R&D, intellectual property and related decision-making departments. It has a global vision, high quality information and deep processing data. In addition to the patent database, there are several other sources of data for forecast technologies, such as social network analysis, scientific literature data, meeting records (Furukawa et al., 2014), etc. Since the TI patent data contains a comprehensive patents and its unique

advantages, the patent data retrieved and downloaded from the TI database is used as a data set.

We retrieve the patent data of convergence emerging technologies, non-convergence emerging technologies, and non-emerging technologies labeled in Section 3.1. For selected technologies that become emerging technologies in a certain year (T year), patent data up to T-1 year is retrieved. Correspondingly, for selected technologies that become non-emerging technologies in a certain year (T year), patent data up to T-1 year is retrieved. The multi-mode emerging technologies are also carrying out corresponding patent data retrieval according to the way push time forward one year.

Taking cloud computing as an example, cloud computing technology first appeared on the Gartner Emerging Technologies Hype Cycles in 2008, which was an emerging technology in that year and was a non-emerging technology since 2015. Using TI as a source of patent data, according to preliminary understanding of cloud computing technology, the search formula was determined as: " ALLD= (cloud computing OR cloud storage OR cloud infrastructure OR private cloud OR public cloud OR Iaas OR PaaS OR SaaS) NOT (IC=A*) NOT (IC=F*) NOT (IP=G01*)". From 2008 to 2014, the search was done on April 15th, 2018, and a total of 8,273 patent documents were retrieved.

3.2.2 Patent features selection

We downloaded the required patent data and extracted features from each patent to describe the differences between convergence emerging technologies, non-convergence emerging technologies, and non-emerging technologies. It is the most critical part of our research, because the accuracy of the forecast depends on a large extent on the correlation of these features with the emerging technology's forecast model. Early studies attempted to define the possible features of the emerging technology generation model. The results of these researches were used as the guideline for the following feature selection. We extracted or derived the following characteristics for patent data corresponding to each technology.

a. Emerging technology features

(1) Number of claims

Break through patents have been found to have a higher renewal rate and higher number of claims (Moore, 2004). Inventors of the important invention are more likely to make claims as much as they can to protect their interest.

(2) Number of citations

Inventors and examiners cite other patents to show dependency of the citing technology to the cited technology (Newman, 2010) as well as to pre-empt any later claims that the cited technology invalidates patentability of the citing technology. In both cases, a high number of citations represents stronger relationship between the citing technology and other technologies. So, a patent likely to be a turning point in a given industry is likely to be distinguished from other patents by the number of citations it receives.

(3) Number of citations made to non-patent literature

Non-patent literature is usually result of the investment by government or large firms, cause many new inventions are implementations of scientific research findings. As such, new inventions are more likely to have a strong connection to non-patent literature. This feature is closely related to the Originality and Science indices used by

(Breitzman and Thomas, 2015) to score patent clusters that are likely to contain new inventions.

(4) Technology Cycle Time (TCT)

TCT is the mean age (in years) of patents cited by a patent. This index measures how fast of the technology in a given technological area changes; a small value of TCT indicates fast changing of technological generations within an area. Within a fast growing technological field, we expect patents containing emerging technologies to have relatively smaller TCT values compared to those merely incrementing on existing technologies. TCT is computed as shown in Eq. (1);

$$TCT_i = median_j \{|T_i - T_j|\} \quad (1)$$

where T_i is the application date of patent i and patents i and j are connected.

(5) Patent class

A patent classification comprises of a main class and a subclass(Kyebambe M N et al., 2017). As the features we have discussed and those we are yet to discuss may vary significantly across patent main classes. We include patent class among the features to harmonize differences among other features across patent classes.

(6) Patent cited times

The reference of patents to prior art and scientific papers is a manifestation of the laws of science and technology development. It embodies the accumulation, continuity, and inheritance of science and technology as well as the intersection and penetration of different disciplines and research levels. . Abert et al. (Abert et al., 1991, Harhoff et al., 1999) have considered that the patent cited times can be directly used as an indicator to identify important patents for enterprises. If a patent is cited by many subsequent patents, it indicates that the invention involved in the patent is a relatively important and important technology. Those patents with high citations are often high quality patents.

(7) Family patent size

All patent documents in the same patent family are called patent family members. Patent family size refers to the number that the same invention obtained patents or filed patent applications in different countries, or the number of countries that the applicant sought patent protection for the same invention. With the increase in the number of countries seeking protection, the cost of patents has also increased. Applicants are more willing to do so for high-tech quality inventions with economic value. At the same time, applying for a patent to another country means the applicant judges that the invention may have international competitiveness. If the patent is finally granted by many countries, it means that the invention can stand the test of many parties and has high technical value. Therefore, the size of the patent family also reflects the economic importance and technical importance of the invention.

(8) The type of IPC

The IPC classification was compiled according to the Strasbourg Agreement on International Patent Classifications signed in 1971. It is currently the only internationally-available tool for classifying and searching patent documents and is an essential tool for countries in the world. The number of IPC classification numbers in a field's patents represents the complexity of the field. The more sub-fields, the higher possibility of convergence.

b. Convergence emerging technology features

(1) The entropy of the node

Entropy denotes the degree of “disorder” in a system and also represents a measure of the quality of life activity process. The concept of entropy is introduced into technology fusion to measure the “quality” of a certain technology in technology fusion. The greater the entropy value, the greater the role played by the technology in technology fusion. The measurement of entropy in technology fusion can provide reference for related companies' R&D priorities. Enterprises can pay attention to related technologies with high entropy and high attention(Lou et al., 2017). Entropy is computed as shown in Eq. (2);

$$E_i = - \sum_j P_{j/i} \log_2 (P_{j/i}) \quad (2)$$

where E_i represents the entropy value of the i -th IPC, and j is an IPC code different from the IPC code i ; $P_{j/i}$ is the number of patents associated with both IPC code i and code j divided by the number of patents associated with IPC code i .

(2) Node strength

Node strength is expressed using the node average weight value, which is the ratio between the unweighted average and the weighted average. Therefore, the unweighted average and the weighted average are respectively measured. The unweighted average represents the number of each node, and the weighted average represents the fusion importance of each node (Akade'miai Kiado' Budapest et al., 2015). The formula is as follows:

$$UAD = \frac{1}{2} \frac{\sum_i l_{ij}}{n}, \text{ where } i \neq j \text{ and } l_{ij} = \begin{cases} 1, & \text{if } w_{ij} > 0 \\ 0, & \text{else} \end{cases} \quad (3)$$

$$WAD = \frac{1}{2} \frac{\sum_i w_{ij}}{n}, \text{ where } i \neq j \quad (4)$$

$$AWL = \sum_i \frac{w_{ij}}{l_{ij}}, \text{ where } i \neq j \text{ and } l_{ij} = \begin{cases} 1, & \text{if } w_{ij} > 0 \\ 0, & \text{else} \end{cases} \quad (5)$$

where l_{ij} is the number of technologies that have convergence with a certain technology i ; w_{ij} is the total number of fusions of a technology and other technologies, that is, the total number that from one node to another nodes, and n is the total number of nodes.

(3) Jaccard coefficient

The Jaccard coefficient(Lou et al., 2017), also known as the Jaccard similarity coefficient, is used to compare the probability of similarity and dispersion in the sample set, which is used to measure link weights. Jaccard coefficient equals the ratio of sample set intersection to sample set union. Jaccard coefficient is computed as shown in Eq. (6);

$$Jaccard \text{ coefficient} = \frac{n(i \cap j)}{n(i \cup j)} \cdot 100\% = w_{ij} \quad (6)$$

where, technology i and technology j are constituted by their technical connotation and technical boundary respectively. The size of the intersection of the two represents the degree of convergence of the technology i and the technology j , that is, the number of links between the technology i and the technology j . The size of the

union represents the total number of patents of the technology i and the technology j , that is, the total number of links from technology i and technology j .

(4) Cross impact

The cross-impact method defines the influence of technology i and technology j $Im\ pact(i, j)$ as a conditional probability $n(j/i)$. The impact value is the ratio of the number of patents contained in both technology i and technology j to the number of patents contained in technology i . It was proposed by Changwoo et al (CHANGWOO GHOI et al., 2007). Grouping links based on cross- impact value will help further analyze the relationships between technologies. The cross- impact value is computed as shown in Eq. (7);

$$Im\ pact(i, j) = \frac{n(i \cap j)}{n(i \cup j)} \quad (7)$$

3.2.3 Training & testing datasets construction

The feature vector of each technology is constructed according to the features of 3.2.2. First, for each of the eight features used in the emerging technologies, the patents corresponding to each technology are calculated and an 8-dimensional vector is directly formed, that is, each technology corresponds to an 8-dimensional vector. Then, for the features of convergence emerging technologies, these features are for IPCs of patents, patents for a certain technology involve multiple IPCs, and there are multiple values. Here, the average value is used as a feature of the convergence emerging technology, and a 4-dimensional vector is formed, that is, each technique corresponds to a 4-dimensional vector. Finally, we combine the features of emerging technologies and the features of convergence emerging technologies, so that a technology feature vector is formed. That is, each technology is represented as a 12-dimensional vector.

Use the data obtained in section 3.2.1 to create a corresponding feature vector for each technology, where the dimension of each vector is one of the features described in section 3.2.2. Our ultimate goal is to train models that can forecast the eigenvectors corresponding to the technology domain in a given year as whether they are emerging in a convergence emerging technologies.

Each technology of the convergence emerging technologies, non-convergence emerging technologies, and non-emerging technologies selected in this paper corresponds to a 12-dimensional feature vector. In order to build the independence of the training set and the test set, the original sample is divided into a training set and a test set in a random manner. The technology feature vectors corresponding to convergence emerging technologies, non-convergence emerging technologies, and non-emerging technologies are randomly selected 70% as training set, the remaining 30% as a test set. The WGAN model is trained using the training set, and data augmentation is performed. The DNN classifier is trained using the enhanced data as the training set, and the DNN classifier is tested using the test set.

3.3 Data augmentation based GAN

The number of sample categories is unbalanced, and it is difficult to get a high-quality model based on statistical machine learning classification methods. At the same time, the total number of samples in each category is small, and it is difficult to effectively train a DNN classification model based on deep learning. We use GAN to enhance the original data samples and generate a large number of identically distributed virtual samples. This effectively solves the problem of small and

unbalanced samples. GAN is a powerful type of generative models (Wang K et al., 2017) introduced in 2014 by Goodfellow (Goodfellow I et al., 2014). GAN comprises two deep architecture functions for the generator and discriminator, which can learn from the trained data in an adversarial fashion simultaneously (Radford A et al., 2015).

The process of generating synthetic samples based on GAN contains two stages in the proposed approach. First, the generator begins to generate original synthetic samples when the loss function of generator and discriminator have converged after training of tens of thousands times. Second, according to GAN's idea of adversarial (McDaniel P et al., 2016), the generator tries to generate synthetic samples which can fake discriminator out, but the discriminator tries to discriminating real samples and synthetic samples. In other words, Original synthetic samples which can fake discriminator out will be the final synthetic samples.

3.4 Forecasting based on deep learning

In the big data environment, deep learning, as the core of the big-data intelligent method, compared with classical statistical machine learning methodologies, has a more complex model structure. The amount and the quality of a data set can significantly affect the deep learning classifier. It requires large-scaled annotated sample data to make model parameters fully optimized and make the performance superior (Goodfellow I et al., 2016).

In order to further enhance the forecast effect of the multi-pattern emerging technologies, after the GAN performs data augmentation on the original samples, a DNN classifier is selected for forecasting. DNN classifier is trained with a large number of synthetic samples generated by GAN to avoid overfitting and is tested with partially independent real samples in the proposed approach. After DNN classifier is trained, we use three multi-classification metrics based on a confusion matrix: accuracy, F-measure, G-mean. The accuracy is the proportion of predictions that are correct, F-measure is the harmonic mean of precision and recall (Sousa L R E et al., 2017), and the G-mean is the geometric mean of recall (Sun Y et al., 2007).

4 Result and Discussion

4.1 Analysis result of proposed approach

Through retrieving and labeling these technologies except the unrecovered technologies, we identify a total of 57 emerging technologies and 48 non-emerging technologies. On the basis of the identified 57 emerging technologies, the emerging technologies were identified through the support of experts and literature data, and 17 convergence emerging technologies were identified. The data is then divided into three categories: convergence emerging technologies, non-convergence emerging technologies, and non-emerging technologies. According to Gartner Emerging Technologies Hype Cycles from 2008 to 2017, 17 convergence emerging technologies, 40 non-convergence emerging technologies, and 48 non-emerging technologies were extracted, as shown in Appendix A. Retrieve and download patents for all convergence emerging technologies, non-convergence emerging technologies, and non-emerging technologies, and calculate the technology feature vector of each technology as the original sample. Table 1 lists the number of patents retrieved for each technology.

Table 1 The number of patents retrieved for each technology

Technology Category	Technology Name	Number of Patents	Technology Name	Number of Patents
CET	Surface Computers	358	Wireless Power	6
	Internet TV	438	Video Search	6
	Home Health Monitoring	19	Interactive TV	6
	Autonomous Vehicles	409	Broadband over Power Lines	6
	IOT	125	Big Data	6
	Social TV	7	3D Scanners	6
	Hybrid Cloud Computing	7	Connected Home	6
	Machine Learning	3060	IOT Platforms	6
	Nanotube Electronics	66		
NCET	Solid State Drives	96	Digital Dexterity	209
	Green IT	71	Virtual Reality	4598
	ebook readers	11	Biochips	1023
	Human Augmentation	9	Affective Computing	65
	Terahertz Waves	401	Electrovibration	6
	Activity streams	106	Digital Security	6
	Virtual Assistants	50	Data Science	6
	Consumer Generated Media	30	Image/Content Recognition	6
	Media Tablets	27	Micro Data Centers	6
	Tangible/Conversational User Interfaces	17	Volumetric & Holographic Displays	6
	Complex event processing	84	802.11ax	6
	QR/Color Code	3246	4D Printing	6
	Group Buying	111	5G	6
	Application Stores	1755	Deep Learning	6
	Blockchain	44	Edge Computing	6
	HTML5	49	Cognitive Computing	6
	NFC (Payments)	5	Mobile Health Monitoring	6
	Neuromorphic hardware	5	Deep Reinforcement Learning	6
	Cloud Computing	5	Consumer Telematics	6
	Crowdsourcing	17	Digital Twin	6
NET	Surface Computers	118	IP Video/Internet Video	6
	Green IT	22	Terahertz Waves	6
	Interactive TV	130	Microblogging	6
	Video Search	86	Broadband over Power Lines	6

Consumer Generated Media	7	QR/Color Code	6
ebook readers	62	Group Buying	6
Wireless Power	2267	Image/Content Recognition	6
Application Stores	434	Internet TV	6
HTML5	89	Crowdsourcing	6
Private Cloud Computing	26	Media Tablets	6
Home Health Monitoring	9	BYOD	6
Predictive Analytics	82	Cloud Computing	6
Big Data	426	3D Scanners	6
Activity streams	166	Complex event processing	6
NFC (Payments)	73	Gamification	6
Machine to Machine Comm. Services	7	Mobile Health Monitoring	6
In Memory Analytics	7	Data Science	6
IOT	1487	Biochips	6
Digital Security	60	Hybrid Cloud Computing	6
Affective Computing	22	3D Bioprinting	6
Cryptocurrencies	8	802.11ax	6
Social Analytics	4	Prescriptive Analytics	6
Social TV	2	3D Flat Panel Displays	6
Micro Data Centers	15	Solid State Drives	6

According to the approach we proposed, we first use the actual sample training set corresponding to the convergence emerging technologies, non-convergence emerging technologies, and non-emerging technologies respectively selected in Section 4.2, and then use the trained GAN to generate 1000 corresponding synthetic samples. Hyperparameters for the GAN were empirically determined. The generator has 2 hidden layers that respectively contains 4 ReLU units, and 12 softmax units are used as output layer, and the dimension of the noise vector z is set to 5. The discriminator also has 2 hidden layers that respectively contains 4 ReLU units, and 1 activation function unit is used as output layer. The WGAN's development environment is tensorflow1.1, and it is trained through GPU. In each iteration of WGAN training, discriminator first iterates 100 times, then the generator iterates 1 time.

After synthetic samples have been generated, synthetic samples are used to train DNN classifier. Then the DNN classifier is tested using the divided 30% of the test set samples. The dimension of classifier's input is 12, which is equal to the number of features in liver cancer samples. The classifier has 2 hidden layers, each containing 32 ReLU units while softmax is used as output layer and cross-entropy is used as loss function. TensorFlow1.1 and GPU are used for training DNN classifier as well and number of iteration is set to 3000 times.

The forecast results of the DNN classifier on the test set data are shown in Table 2. In the test set, the 4 of 5 convergence emerging technologies are forecasted to be

correct, and 1 is non-emerging technologies. The 8 of 10 non-convergence emerging technologies are forecasted to be correct, and 1 is non-emerging technologies, and 1 is convergence emerging technologies. The 7 of 10 non-emerging technologies are forecasted to be correct, and 2 are non-convergence emerging technologies, and 1 is convergence emerging technologies. According to the results, there are a total of 15 emerging technologies for the 5 convergence emerging technologies and 10 non-convergence emerging technologies, and only 2 technologies are identified as non-emerging technologies with an accuracy rate of 86.67%, which indicates that the forecast model can forecast emergence of emerging technologies with an accuracy of 86.67% a year before they emerge. Among all emerging technologies, the number of correctly forecast convergence emerging technologies and non-convergence emerging technologies is 12 with an accuracy rate of 80.00%, which indicates that the forecast model can forecast emergence of emerging technologies with an accuracy of 80.00% a year before they emerge.

Table 2 The experiment results of DNN classifier for the test set

	Forecast			Total
	CET	NCET	NET	
CET	4	0	1	5
NCET	1	8	1	10
NET	1	2	7	10
Total	6	10	9	25

4.2 Evaluation of proposed approach

In order to verify the effectiveness of our proposed method, we used the statistical classifiers Random Forest (RF) and Naive Bayes (NB) for comparison experiments. As a classic machine learning classifier, RF and NB have higher classification accuracy and better generalization performance than machine learning classifiers. The results of comparative experiments in the three categories of CET, NCET, and NET are shown in Table 3.

Table 3 The results of classifier comparison experiment

Model	Accuracy	F-measure	G-mean
NativeBayes	0.4000	0.4150	0.4160
RandomForest	0.5200	0.4981	0.4932
GAN-DNN	0.7600	0.7573	0.7652

From Table 3, we can see that on the same data set, the Accuracy, F-measure, and G-mean of RF classifiers and NB classifiers are lower than the GAN-DNN proposed by us. The comparison of evaluation indicators shows that the classification quality of classical classifiers RF and NB based on statistics is lower than the combination of the GAN-based data augmentation algorithm and the DNN-based deep learning algorithm proposed by us. The comparison test results show that GAN combined with DNN deep learning method can effectively solve the forecast problems of CET, NCET, and NET.

4.3 Discussion

According to the above results, the proposed method of data augmentation combined with deep learning has achieved good results in the forecast of CET and NCET. This result has important significance for forecasting emerging technologies.

First, there are multiple patterns for the emergence of emerging technologies. This paper has effectively explored the forecast of convergence emerging technologies and non-convergence emerging technologies, and has also provided an effective research method for forecasting other emerging patterns of emerging technology. Second, through the method proposed by us, we can effectively transform the emerging technology forecast problem into a supervised machine learning classification problem, providing an automated solution for forecasting emerging technologies. Finally, the deep learning and data augmentation methods effectively solve the data problems in the forecast of CET and NCET using supervised machine learning methods. This also provides ideas for the application of artificial intelligence methods such as data augmentation and deep learning in forecasting emerging technologies.

5 Conclusions

In this paper, we proposed an approach based on deep learning and data augmentation that can forecast the CET and NCET 1 year before they emerge with high quality. Compared with the traditional methods, we not only forecast the emerging technology from the generation pattern, but also effectively transform the forecasting question of emerging technologies into a multi-classification supervised machine learning question, which can automatically forecast convergence emerging technologies and non-convergence emerging technologies. Furthermore, the effective application of artificial intelligence methods such as deep learning and data augmentation in this research also provides an effective way for artificial intelligence technology to be applied in forecasting emerging technologies.

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References

- Abert M B, Avery D, Narin F, et al. Direct validation of citation counts as indicators of industrially important patents[J]. *Research Policy*, 1991, 20(3): 251-259.
- Akade'miai Kiado' Budapest, Hungary. Technology Convergence: What Developmental Stage are we in? [J]. *Scientometrics*, 2015, 104(3): 841-871.
- Breitzman, A., Thomas, P., 2015. The emerging clusters model: a tool for identifying emerging technologies across multiple patent systems. *Res. Policy* 44, 195–205.
- CHANGWOO GHOI, SEUNGKYUM KIM, YONGTAE PARK. A patent-based Cross Impact Analysis for Quantitative Estimation of Technological Impact: the Case of Information and Communication Technology[J]. *Technological Forecasting & Social Change*, 2007 (74) : 1296-1314.
- Cho, C., Yoon, B., Coh, B.Y., Lee, S., 2016. An empirical analysis on purposes, drivers and activities of technology opportunity discovery: the case of Korean SMEs in the manufacturing sector. *R&D Manag.* 46 (1), 13–35.
- Choi, S., Jun, S., 2014. Vacant technology forecasting using new Bayesian patent clustering. *Tech. Anal. Strat. Manag.* 26 (3), 241–251.
- Curran C S, Bröring S, Leker J. Anticipating converging industries using publicly available data[J]. *Technological Forecasting & Social Change*, 2010, 77(3):385-395.
- Daim, T.U., Rueda, G., Martin, H., Gerdtsri, P., 2006. Forecasting emerging technologies: use of bibliometrics and patent analysis. *Technol. Forecast. Soc. Chang.* 73(8), 981–1012.
- Drew, S.A., 2006. Building technology foresight: using scenarios to embrace innovation. *Eur. J. Innov. Manag.* 9 (3), 241–257.
- Furukawa, T., Mori, K., Arino, K., Hayashi, K., Shirakawa, N., 2014. Identifying the evolutionary process of emerging technologies: a chronological network analysis of World Wide Web conference sessions. *Technol. Forecast. Soc. Chang.* 91, 280–294.
- Goodfellow I, Bengio Y, Courville A. Deep Learning[M]. The MIT Press, 2016.
- Goodfellow I, Pougetabadie J, Mirza M, et al. Generative Adversarial Nets[J]. *Advances in Neural Information Processing Systems*, 2014:2672-2680.
- Harhoff D, Narin F, Schere F M, et al. Citation frequency and the value of patented inventions[J]. *The Review of Economics and Statistics*, 1999(8): 511-515.
- Hsieh, C.H., 2013. Patent value assessment and commercialization strategy. *Technol. Forecast. Soc. Chang.* 80 (2), 307–319.
- Jin, G., Jeong, Y., Yoon, B., 2015. Technology-driven roadmaps for identifying new product/ market opportunities: use of text mining and quality function deployment. *Adv. Eng. Inform.* 29 (1), 126–138.
- Kim, J., Park, Y., Lee, Y., 2016. A visual scanning of potential disruptive signals for technology roadmapping: investigating keyword cluster, intensity, and relationship in futuristic data. *Tech. Anal. Strat. Manag.* 1–22.
- Kong D, Zhou Y, Liu Y, et al. Using the data mining method to assess the innovation gap: A case of industrial robotics in a catching-up country[J]. *Technological Forecasting and Social Change*, 2017, 119: 80-97.
- Kyebambe M N, Cheng G, Huang Y, et al. Forecasting emerging technologies: A supervised learning approach through patent analysis[J]. *Technological Forecasting and Social Change*, 2017, 125: 236-244.
- Lee, C., Song, B., Park, Y., 2015. An instrument for scenario-based technology roadmapping: How to assess the impacts of future changes on organisational plans. *Technol. Forecast. Soc. Change.* 90, 285–301.

Lee, S., Yoon, B., Lee, C., Park, J., 2009. Business planning based on technological capabilities: patent analysis for technology-driven roadmapping. *Technol. Forecast. Soc. Chang.* 76 (6), 769–786.

Li, X., Zhou, Y., Xue, L., Huang, L., 2015. Integrating bibliometrics and roadmapping methods: a case of dye-sensitized solar cell technology-based industry in China. *Technol. Forecast. Soc. Chang.* 97, 205–222.

Lou Y, Yang, P P, Huang L C, Miao H, et al. Patent-based technology fusion measurement method——using the fusion of information technology and electric vehicle technology as an example[J].*Journal of Modern Information*,2017,37(08):142-153.

Ma, J., Porter, A.L., 2015. Analyzing patent topical information to identify technology pathways and potential opportunities. *Scientometrics* 102 (1), 811–827.

Mcdaniel P, Papernot N, Celik Z B. Machine Learning in Adversarial Settings[J]. *IEEE Security & Privacy*, 2016, 14(3):68-72.

Moore, K.A., 2004. Worthless patents. <http://dx.doi.org/10.2139/ssrn.566941>.

Narin, F., 1994. Patent bibliometrics. *Scientometrics* 30 (1), 147–155.

Newman, M., 2010. *Networks: An Introduction*. Oxford University Press.

Pennings J M, Puranam P. Market convergence & firm strategies: towards a systematic analysis[J]. Retrieved August, 2000.

Phaal, R., Farrukh, C.J., Probert, D.R., 2004. Technology roadmapping—a planning framework for evolution and revolution. *Technol. Forecast. Soc. Chang.* 71 (1), 5–26.

Porter, A.L., Roper, A.T., 1991. *Forecasting and Management of Technology* vol. 18. John Wiley & Sons.

Radford A, Metz L, Chintala S. Unsupervised Representation Learning with Deep Convolutional Generative Adversarial Networks[J]. *Computer Science*, 2015.

Rowe, G., Wright, G., 2001. Expert opinions in forecasting: the role of the Delphi technique. *Principles of forecasting*. Springer, US, pp. 125–144.

Shen, Y.C., Chang, S.H., Lin, G.T., Yu, H.C., 2010. A hybrid selection model for emerging technology. *Technol. Forecast. Soc. Chang.* 77 (1), 151–166.

Sousa L R E, Miranda T, Sousa R L E, et al. The Use of Data Mining Techniques in Rockburst Risk Assessment[J]. *Engineering*, 2017, 3(4):552-558.

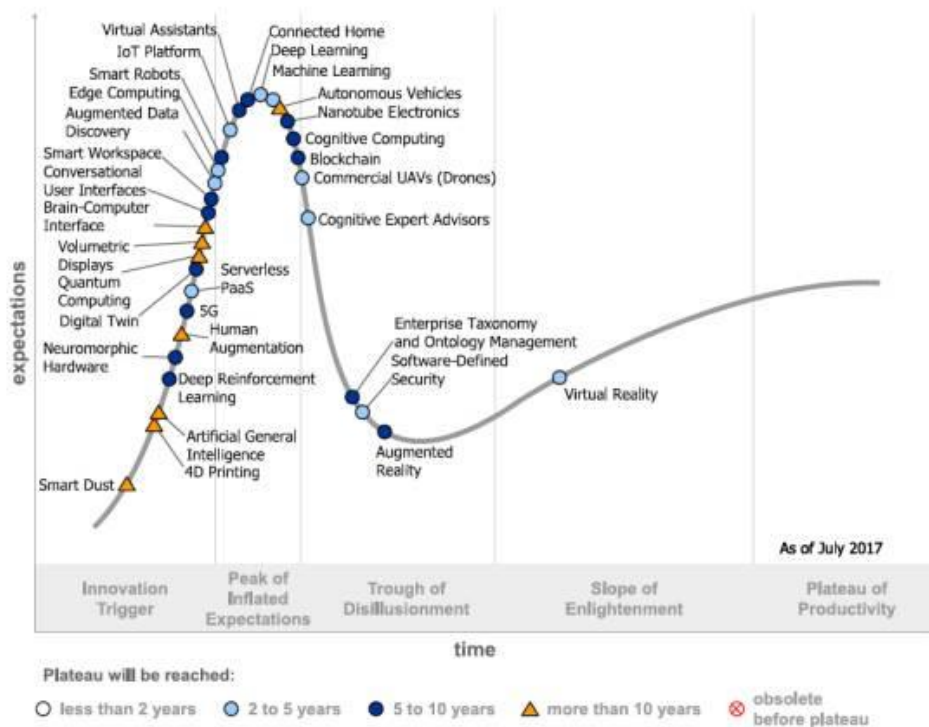
Stieglitz N. Strategie und Wettbewerb in konvergierenden Märkten[J]. 2004.

Sun Y, Kamel M S, Wong A K C, et al. Cost-sensitive boosting for classification of imbalanced data[J]. *Pattern Recognition*, 2007, 40(12):3358-3378.

Walsh, S.T., 2004. Roadmapping a disruptive technology: a case study: the emerging microsystems and top-down nanosystems industry. *Technol. Forecast. Soc. Chang.* 71 (1), 161–185.

Wang K, Gou C, Duan Y, et al. Generative adversarial networks: introduction and outlook[J]. *IEEE/CAA Journal of Automatica Sinica*, 2017, 4(4):588-598.

Appendix A



2017 Gartner Emerging Technologies Hype Cycles

Appendix B

2008 - 2017 CET, NCET, NET List

Year	CET	NCET	NET
2008	Surface Computers	Solid State Drives, Green IT, Cloud Computing	
2009	Wireless Power, Internet TV, Video Search, Home Health Monitoring	ebook readers, Human Augmentation	Solid State Drives
2010	Interactive TV, Autonomous Vehicles, Broadband over Power Lines	Terahertz Activity streams, Virtual Assistants, Consumer Generated Media, Media Tablets, Tangible/Conversational User Interfaces	Surface Computers, IP Video/Internet Video, Green IT
2011	IOT, Big Data, Social TV	Image/Content Recognition, QR/Color Code, Group Buying, NFC (Payments)	Terahertz Interactive TV, Microblogging, Search, Broadband over Power Lines, Consumer Generated Media, 3D Flat

Panel Displays

2012	3D Scanners, Hybrid Cloud Computing	Application Complex processing, Crowdsourcing, Volumetric & Holographic Displays, Consumer Telematics	Stores, event HTML5, & Social TV	QR/Color Code, ebook readers, Group Buying, Social TV
2013		Virtual Reality, Biochips, Affective Computing, Electro vibration, Mobile Health Monitoring		Wireless Power, Image/Content Recognition, Application Stores, Internet TV, HTML5, Crowdsourcing, Private Cloud Computing, Media Tablets, Home Health Monitoring, BYOD, Social Analytics
2014	Connected Home	Digital Security, Data Science		Predictive Analytics
2015	Machine Learning, IOT Platforms	Digital Dexterity, Micro Data Centers		Cloud Computing, Big Data, 3D Scanners, Activity streams, Complex event processing, NFC (Payments), Gamification, Machine to Machine Comm. Services, In Memory Analytics, Mobile Health Monitoring, Data Science, Prescriptive Analytics
2016	Nanotube Electronics	Blockchain, 802.11ax, 4D Printing, Neuromorphic hardware		IOT, Biochips, Digital Security, Hybrid Cloud Computing, Affective Computing, 3D Bioprinting, Cryptocurrencies
2017		5G, Deep Learning, Edge Computing, Cognitive Computing, Digital Twin, Deep Reinforcement Learning		802.11ax, Micro Data Centers

DARPA-BAA-16-24:
Targeted Neuroplasticity Training (TNT) BAA
Frequently Asked Questions

Version 1.2
Last Updated: 5/20/16

CONTENTS

PROPOSAL WRITING	2
PROGRAM STRUCTURE	4
PROPOSERS DAY	5
Definitions	5
Technical Area 1 Scope	6
Technical Area 2 Scope	7
COST PROPOSAL.....	9

PROPOSAL WRITING

1. Are proposers required to respond to both TA 1 and TA 2?

Yes. Page 5 of DARPA-BAA-16-24 states that “proposers are required to respond to both technical areas in full.” Partial proposals will not be considered.

2. Is it possible to propose to a portion of a Technical Area?

No, each TA is indivisible. If proposers feel that their research interests and expertise cannot fully satisfy the objectives of a given TA, they should consider teaming with other researchers.

3. Is DARPA interested in large teams or many small teams?

This program will likely require large teams in order to adequately address the requirements of both TA 1 and TA 2. Page 7 of DARPA-BAA-16-24 states that “it is expected that TA1-2 teams will be multidisciplinary, spanning backgrounds such as cognitive neuroscience, neural plasticity, electrophysiology, systems neurophysiology, biomedical engineering, human performance, and computational modeling. Proposer teams are strongly encouraged to include expertise across these fields, as well as with industry partners that can develop commercial applications based on outputs of the TNT program. The breadth and depth of relevant expertise in the technical team will be an important consideration in the evaluation of proposals.”

4. What has DARPA done to facilitate teaming?

It is anticipated that teaming will be necessary to cover the wide range of animal and human tasking required in the TNT BAA. DARPA encourages collaboration and use of the TNT program’s teaming website to facilitate the formation of teams with necessary expertise. Proposers interested in teaming should submit a profile through the teaming website. The profile will contain such information as your research interests, capabilities and expertise, as well as areas in which you are seeking collaborators and your contact information so that other teams may reach out to you. The teaming website will remain live until the close of the BAA and is located at: <https://team.sainc.com/TNT/home.aspx>

5. May I collaborate with a Government partner?

Yes, FFRDCs and government entities can submit proposals (as prime or subcontractor) if they meet certain criteria specified in BAA Section 3.1.1.

6. May I submit (either as PI, co-I, or subcontractor) multiple proposals?

Yes. However, be mindful that you are not over-allocated if multiple proposals are selected for award.

7. Can proposals list co-PIs?

All proposals must list one lead PI serving as a POC for all contractual matters. Proposals may list Co-PIs as key personnel, but the PI will have sole responsibility and authority to negotiate contract matters.

8. How will the proposals be evaluated?

A team of government reviewers will evaluate applications based on the evaluation criteria described in Section 5.1 of DARPA-BAA-16-24. The reviewers are selected based on their relevant scientific or technical expertise. Reviewers typically represent multiple government agencies, including FDA, NIH, NSF, NIST, and DoD research organizations. The review criteria are listed in the BAA and are rank ordered, with the most important criterion being listed first.

9. Should I submit via DARPA's BAA website or grants.gov?

Per the BAA, "Proposers requesting grants or cooperative agreements may submit proposals through one of the following methods: (1) hard copy mailed directly to DARPA; or (2) electronic upload per the instructions at <http://www.grants.gov/applicants/apply-for-grants.html>." Regardless of the submission mechanism, DARPA reserves the right to award proposals as contracts, grants, or cooperative agreements.

10. I want to submit my proposal via grants.gov. Attachment 4 to the BAA is required to be submitted as an editable MS Excel spreadsheet. However, I cannot upload an MS Excel file to grants.gov. In addition, I can't upload the MS Word version of the SOW, and the MS PowerPoint version of the summary slides. What should I do?

Please submit attachment 4, the SOW, and summary slides as PDF files on grants.gov. The BAA coordinator (DARPA-BAA-16-24@darpa.mil) will follow up with you after your proposal is submitted to request the MS Excel, Word, and PowerPoint files via email.

11. Do page limits include table of contents, list of figures, and list of tables?

No. Please see section 4.3 of DARPA-BAA-16-24 for a description of the content encompassed by the page limits.

12. Are teaming agreements with subcontractors (requested in Section 2.C, page 21) included in the page count?

No.

13. Is an IRB draft protocol required with submission, or can we simply submit a plan for constructing and submitting the protocol?

You need not submit a draft protocol but you should prepare a schedule that allows sufficient time to obtain approvals from your local IRB and then secondary review by DoD. The main point is to make sure you allow time in your schedule for the DoD review since that process can't start until the award is finalized.

14. If a Human Research Study/ Draft Protocol is included with the submission, would this be included in page count, or could it be included as an attachment?

Protocol documents should be included as attachments and will not count towards the page limit.

15. Are proposers limited to only US citizens and US institutions?

No. We welcome the best ideas and research from any source. PIs, co-Is, students, post-docs, employees, subcontractors, and institutions do not have to be US citizens or based in the US. All proposed and awarded work must comply with US laws and regulations (including animal and human subjects use).

16. What is meant by "Proposal Validity Period?"

The period of time within which a proposal submitted by an organization, in response to a solicitation, must remain unchanged. After this period, if the contract has not been awarded, the firm is at liberty to change both the technical and/or financial proposals. Any attempt by the firm to change its proposal before the end of the proposal validity period is unacceptable and may result in the rejection of the proposal.

17. Section 6.2.5 of DARPA-BAA-16-24 indicates that Offerors are required to submit a small business subcontracting plan with their proposal. Although the elements of the plan are outlined in FAR 19.704, is there a corresponding DARPA form that we could utilize?

No.

18. Is a subcontracting plan needed for every subcontract that will be a part of the overall project?

No. FAR 19.702(a) (1) (which can be accessed using the following link:

http://www.acquisition.gov/far/current/html/Subpart%2019_7.html) provides more details regarding the description and content of the plan.

19. Is it possible to submit the application without the subcontracting plan and submit that as part of any negotiations that happen later should an award be made?

Section 6.2.5 of DARPA-BAA-16-24 indicates, "Each proposer who submits a contract proposal and includes subcontractors is required to submit a subcontracting plan in accordance with FAR 19.702(a) (1) and should do so with their proposal."

20. Can a proposal be submitted without DUNS and SAM numbers?

Section 6.2.8 of DARPA-BAA-16-24 indicates, "Unless the proposer is exempt from this requirement, as per FAR 4.1102 or 2 CFR 25.110 as applicable, all proposers must be registered in the System for Award Management (SAM) and have a valid Data Universal Numbering System (DUNS) number prior to submitting a proposal." This clause applies specifically to the organization submitting the proposal.

21. Do subcontractors need to register on the submission page, or will all of that be on the prime contractor?

The prime is responsible for proposal submission. However, if the subcontractor wants to provide more than what is provided through the prime contractor (such as proprietary information) then the subcontractor may create their own account and submit information separately.

22. Can a government proposer partner with a university or industry?

DARPA often partners with government agencies, either directly or as a subcontractor. Government entities interested in responding (as prime or subcontractors) should carefully review Section 3.1.1 of the BAA with regard to their eligibility.

23. The Technical SOW template and the Cost Worksheet numbering system do not align. Can we use a standardized numbering system so that Phase 1 tasks begin with "1" and Phase 2 tasks start with "2"?

Yes.

PROGRAM STRUCTURE

24. Regarding the period of performance, is it expected that TA1 and TA2 should run concurrently or consecutively throughout the 4-year program?

TA1 and TA2 studies will run concurrently.

25. What is the anticipated program start date?

Actual start dates will depend on the time needed to complete the contracting process. We recommend that you assume a start date of January 1, 2017, but please note that the actual start date may be sooner or later.

26. Does the experimental data need to be collected on actual DoD tasks (e.g., Intelligence Analysis of sensitive materials) rather than analytic tasks that entail only non-sensitive materials?

Proposers are welcome to use experimental tasks that are well-validated in the literature to represent the fundamental building blocks of DoD skills. It is anticipated that performers will publish their results in peer-reviewed journals.

PROPOSERS DAY

27. Where can I access DARPA presentations from the TNT proposers day that was held in Arlington, VA on 8 April 2016?

DARPA presentations will be uploaded to the teaming website: <https://team.sainc.com/TNT/home.aspx>

28. Where can I access blitz presentations from the TNT proposers day that was held in Arlington, VA on 8 April 2016?

You are welcome to reach out to blitz presenters directly to request a copy of their presentation. If you attended the TNT proposers day, you should have received a packet during registration that includes the blitz presenters' names and organizations, along with contact information for attendees who allowed DARPA to distribute their information. If you did not attend the TNT proposers day or receive this information, please reach out to DARPA-BAA-16-24@darpa.mil for a copy of these files.

You can also find more information on potential proposers' capabilities and interact with them at the teaming website: <https://team.sainc.com/TNT/home.aspx>

Definitions

29. What is the TNT program's definition of "minimally invasive?"

DARPA-BAA-16-24 uses the term "noninvasive." DARPA considers "noninvasive" devices to be ones that are not placed under the skin.

30. What is meant by "control group without stimulation" from section 1.2.1 under TA1 Phase I Goals, or "unstimulated control group" from section 1.2.2 under TA2 Phase II goals and Table 2?

DARPA considers "control group without stimulation" or "unstimulated control group" as a subgroup that gets sham or non-treated controls.

31. What is meant by "established behaving animal models" mentioned in section 1.1.2 of DARPA BAA 16-24?

DARPA considers "established behaving animal models" as those that are found in current scientific literature. If the development of new behaving animal models are needed in order to respond to DARPA-BAA-16-24, please provide scientific justification in the proposal.

32. Is the spinal cord considered central nervous system (CNS) or peripheral nervous system (PNS) in this program?

DARPA considers the spinal cord to be part of the PNS for the purposes of the TNT program. Nerves or nervous tissue located outside the cranium are considered peripheral for the TNT program as well.

Technical Area 1 Scope

33. Does TA1 need to include single cell recordings? Is EEG a viable approach?

The answer depends on the central hypothesis of the proposal. However, proposers are encouraged to scientifically justify their approach.

34. Can proposers begin human subjects research without working with an animal model?

Section 1.1.2 of DARPA-BAA-16-24 indicates, “DARPA encourages studies that will record activity in large neural populations at single neuron resolution across multiple brain regions simultaneously for extended periods of time.” If proposers can convince DARPA that they can gain a deep neuroscience insight within humans only in TA1, DARPA will consider this approach. However, DARPA is skeptical that this approach is possible and recommends partnering with those that have appropriate animal expertise.

35. Does DARPA have a preference for rodent, nonhuman primate, or other animal models?

Section 1.1.2 of DARPA-BAA-16-24 indicates that, “established behaving animal models” should be used. Proposers should choose the appropriate animal model for the chosen tasks and ensure scientific justification for their choice.

36. How parallel do human and animal studies need to be? What if there is not a simple counterpart for tasks in animals?

DARPA encourages proposers to use their best judgement. Proposers are encouraged to look to literature to identify appropriate models when possible. Wherever possible, proposers should match stimuli parameters, locale, etc. between animal models and human studies.

37. Can proposers break complex human tasks into relevant subtasks that would be more relevant for animal models?

Yes, that would be an appropriate approach.

38. Most training and learning is not usually retained for long periods of time, how does this impact the expectations of the TNT program?

Table 1 of DARPA BAA 16-24 indicates the requirement of “retention evaluated > 30 days after training” within TA1 Phase II.

39. What about ceiling effects? Is DARPA asking for a large increase in ability?

DARPA encourages proposers to conduct research which allows them to determine what the limits are for the proposed approaches. DARPA would also like to remind proposers that they can demonstrate an improvement in the rate of learning, not necessarily the overall proficiency.

40. Does DARPA-BAA-16-24 consider fMRI and other imaging techniques to be adequate for measuring brain activity?

Section 1.1.2 of DARPA BAA 16-24 states: “Functional neuroimaging and/or electrophysiology may be used to measure the location and extent of changes in brain activity during training, with and without

neurostimulation.” DARPA believes that fMRI is appropriate for humans, but encourages proposers to utilize a higher resolution imaging technique for animal models.

Technical Area 2 Scope

41. Is DARPA interested in rehabilitation applications?

No. Section 1.1 of DARPA BAA 16-24 states: “Recent success with this approach has been demonstrated in clinical rehabilitation studies, utilizing peripheral neurostimulation delivered through implanted electrodes. However, while invasive approaches may be justified for treating people with medical conditions, noninvasive methods are preferred for use in healthy individuals.”

42. May proposers use existing neurologically impaired clinical populations or only able-bodied individuals?

Section 1.1.2 of DARPA BAA 16-24 states: “When relevant clinical populations are readily available, DARPA encourages investigators to test and compare effects of stimulation delivered via implanted and non-implanted electrodes.” Both clinical and healthy populations may be used to address biological mechanisms, but the end goal of the proposed approach should be applications for healthy individuals.

43. The education of military personnel varies greatly, what intelligence level should we be targeting in this program?

Proposers should choose the appropriate baseline for their selected domain or target application.

44. Is memory out of scope for cognitive applications?

Proposers should not focus exclusively on memory. However, cognitive aspects that include memory are within scope of DARPA-BAA-16-24.

45. What aspects of military activity are related to cognitive functions (rather than being mostly physical)?

Section 1.1.2 of DARPA-BAA-16-24 states: “Proposers are expected to address multiple cognitive skills and are encouraged to tie proposed skills to specific Department of Defense (DoD) use cases, such as foreign language learning, intelligence analysis, tactical operation center control, and cryptography.” The primary focus of DARPA-BAA-16-24 is on the neural activity underlying these cognitive functions.

46. Does unstimulated controls have to be sham or can it be a stimulation parameter outside the hypothesis?

The answer depends on the proposed applications, but proposers need to scientifically justify their choice of controls.

47. Many groups consider no stimulation as a poor control for humans and believe a low dose stimulation is better, would this be appropriate?

It depends on the proposed hypothesis – proposers must demonstrate that low stimulation has no effects.

48. Is there requirement for transition to commercially available applications? What are the transition paths?

Section 1.1.2 of DARPA-BAA-16-24 states: “Proposers should address how proposed tasks relate to the real-world tasks within specific DoD use cases. Specifically, proposers should assess the similarity between a proposed task and real-world task environment, stimuli, and response mechanisms.”

Although DARPA has transition plans for technologies developed by the TNT program, the specifics of the plan cannot be determined until TNT teams are selected. DARPA-BAA-16-24 does not require a transition plan, but proposers are welcome to include transition plans for their specific technologies in the proposal.

49. What is the outcome of the proposal, or function that DARPA is looking for? What minimal set of skills or improvements is DARPA looking for?

Section 1.1.2 of DARPA-BAA-16-24 states: “Cognitive skills of interest to TNT include, but are not limited to, sensory perception, comprehension, decision-making, motor intent. Work aimed at enhancing general memory functions is out of scope.” and “Proposers are expected to address multiple cognitive skills and are encouraged to tie proposed skills to specific Department of Defense (DoD) use cases, such as foreign language learning, intelligence analysis, tactical operation center control, and cryptography.” The focus of the proposal should be on science and technology. DARPA wants to emphasize that the focus of this program is on plasticity; the application is of secondary importance and can be decided by the proposer. Keep in mind that the BAA states a goal of 30% improvement in the cognitive function proposed.

50. Can teams propose for multiple cognitive skills or domains?

Yes, Section 1.1.2 of DARPA-BAA-16-24 states: “Cognitive skills of interest to TNT include, but are not limited to, sensory perception, comprehension, decision-making, motor intent. Work aimed at enhancing general memory functions is out of scope.” and “Proposers are expected to address multiple cognitive skills and are encouraged to tie proposed skills to specific Department of Defense (DoD) use cases, such as foreign language learning, intelligence analysis, tactical operation center control, and cryptography.”

51. Is DARPA looking for ways to evaluate potential susceptibility to proposed stimulation training protocols?

Ways to evaluate potential susceptibility to proposed stimulation training protocols are not an explicit aim of the TNT program, but can be included in the proposal.

52. Is it appropriate to threshold human subjects based on an aptitude test prior to testing the stimulation paradigm?

The answer depends on the hypothesis and outcome measures of each individual proposal.

53. How important is the subject motivation for screening of subject selection?

The answer is specific to the focus of each individual proposal. DARPA simply asks that subject screening approaches be scientifically justified.

54. Is thermal stimulation in scope?

Thermal stimulation is in the scope of DARPA-BAA-16-24 if proposers can scientifically justify its ability to influence plasticity.

55. Would military personnel who need traumatic brain injury (TBI) treatment be of interest?

TBI is not the focus of TNT. Section 1.1.2 of DARPA BAA 16-24 states: “When relevant clinical populations are readily available, DARPA encourages investigators to test and compare effects of stimulation delivered via implanted and non-implanted electrodes.”

56. Is it possible to evaluate side effects with such a short program duration?

Evaluating and eliminating possible side-effects are a major objective of the TNT program. Section 1.1.1 of DARPA-BAA-16-24 states that one research objective is to “optimize noninvasive stimulation methods and training protocols for long-term retention without negative side effects.” Section 1.1.2 of DARPA-BAA-16-24 states: “Potential side effects should be identified within the proposal. Proposers should include research plans to assess and mitigate these side effects within the program.” Table 1 of DARPA-BAA-16-24 indicates that one of milestones and deliverables of Phase I is to “Provide stimulation parameter map for identified side effects.” Proposers should consider building tests into the experimental design that monitor off target effects or negative side effects.

57. Will proposers be penalized if their background is in clinical populations and not healthy humans, since the end goal is healthy adults?

No. While the end goal is healthy humans, DARPA recognizes the relevance of existing clinical patient populations to learn about biology and mechanisms. Section 1.1.2 of DARPA BAA 16-24 states: “When relevant clinical populations are readily available, DARPA encourages investigators to test and compare effects of stimulation delivered via implanted and non-implanted electrodes.” Both clinical and healthy populations may be used to address biological mechanisms, but the end goal of the proposed approach should be applications for healthy individuals.

58. DARPA-BAA-16-24 is precluding transcranial alone. What about in conjunction with peripheral stimulation? What about a multimodal approach, or additive between the two approaches?

The primary focus is on peripheral stimulation. Proposals that use peripheral stimulation as only an adjunct to transcranial stimulation are not of interest. Transcranial stimulation used in conjunction with peripheral stimulation should be justified scientifically and only proposed as an adjunct to peripheral stimulation.

59. If a proposers local IRB is under the DoD, does human use require a secondary DoD level IRB approval?

Yes. Please refer to section 6.2.2 of DARPA BAA-16-24 for more information.

60. Can human subjects research be performed outside of US as part of this program?

Yes. However, proposers are encouraged to allow sufficient time in their proposals to complete the secondary DoD-level IRB approval, which applies even outside the US. Please refer to section 6.2.2 of DARPA BAA-16-24 for more information.

COST PROPOSAL

61. How important is the Cost Proposal?

The cost proposal is very important. Proposers who do not submit a well-constructed cost proposal may be considered nonresponsive to DARPA-BAA-16-24. A well prepared cost proposal is described in section 4.4 (specifically pages 23-26) of DARPA-BAA-16-24.

62. Is the budget template (attachment 4) mandatory?

No. Attachment 4 was created to aid proposers in meeting the requirements of the BAA. Section 4.4 (specifically pages 23-26) and attachment 1 (the cost proposal checklist) of DARPA-BAA-16-24 asks proposers to provide information that is covered by the template.

63. If I choose to use Attachment 4, will it form the entirety of my cost proposal?

No. Although the template encompasses a large portion of what section 4.4 (specifically pages 23-26) and attachment 1 (the cost proposal checklist) of DARPA-BAA-16-24 asks for, it does not include everything needed in the cost proposal. Be certain to carefully review pages 23-26 of DARPA-BAA-16-24 to understand the requirements for a complete cost proposal.

64. How can I access the tutorial videos for Attachment 4?

DARPA has created the following tutorial videos to assist you in completing Attachment 4 for the TNT BAA:

- Part I: Example Budget: <http://youtu.be/Np-OHcLnfdA>
- Part II: Editing and Customizing the Blank Budget Template: <http://youtu.be/Obr7H8bYIG4>

You will notice that these videos were made specifically for the HAPTIX BAA (DARPA-BAA-14-30). Although the HAPTIX BAA is mentioned, the instructions are also applicable to the TNT BAA.

65. I am not very familiar with how to use MS Excel. What concepts are key to understand in order to use the template?

Although the template can appear very detailed and complex, it is compiled using very simple MS excel concepts. It is necessary to understand the formulas for basic arithmetic functions, how to link data within and across tabs, and absolute reference. A helpful tutorial on absolute reference can be accessed through the following link: <http://youtu.be/NmVMjQzseLA>.

66. Do I have to provide a budget for both phases? How can I know what my expenses will be four years from now?

Please provide complete budgets for both phases. All phases should contain the same level of detail that is requested in section 4.4 (specifically pages 30-32) of DARPA-BAA-16-24. Put together a plan that you feel will be a likely course for the entire proposed effort. Awarded contracts will be only for Phase I with pre-negotiated options for the subsequent Phase(s). These options will be executed (i.e. turned on) if DARPA is satisfied with your results and if DARPA has available funds for your effort. By negotiating these options within the scope of the DARPA-BAA-16-24, we can avoid substantial delays and problems that might arise from beginning negotiation on subsequent phases at a later date.

There will be opportunities to revise contracts at the awarding of each option. All parties will find it reasonable to update their expected costs, scope, and deliverables based on the progression of TNT. These re-negotiations will require the concurrence of all parties and will not be unilateral.

67. Can DARPA partially fund a proposal?

Yes. DARPA reserves the right to fully fund or partially fund a proposal. More details can be found on page 10 of DARPA-BAA-16-24.

68. What is entailed in a PI Meeting?

Section 6.2.1 of DARPA-BAA-16-24, "1. Meeting and Travel Requirements" describes PI Meetings. Briefly, PIs are expected to meet with the Program Manager and the other PIs awarded under the TNT program. These meetings will occur roughly once per year. It is expected that PIs will freely share their research results with each other and the Program Manager.

69. Should proposers budget for collaboration with parties not included in the proposed team?

If proposers plan to support work performed by another team (e.g. an informal collaboration with another group working in a different technical area), then indicate such effort as a separate task or sub-task, with associated costs itemized for those tasks and subtasks.

70. How can we budget for travel? We don't know where DARPA meetings will be located.

You should plan on sending key personnel to at least one PI meeting per year at a major US city, as well as other mission-relevant events. Be sure to justify the relevance of the non-DARPA events. A common practice is to assume that the PI meeting location will alternate between the west and east coasts (e.g. California and Washington, DC). Costs can be estimated using standard lodging and per diem rates posted at <http://www.gsa.gov/perdiem>. There will be no registration fee for DARPA-sponsored meetings.

71. Can DARPA address the issue of cost sharing? If proposers want to be selected for award, should they consider cost-sharing? What about in-kind cost sharing?

Cost-sharing is considered, but not required. Section 3.2 of DARPA-BAA-16-24 provides more details.



Broad Agency Announcement
Targeted Neuroplasticity Training (TNT)
BIOLOGICAL TECHNOLOGIES OFFICE
DARPA-BAA-16-24

April 1, 2016

TABLE OF CONTENTS

PART I: OVERVIEW INFORMATION	3
PART II: FULL TEXT OF ANNOUNCEMENT	4
1. Funding Opportunity Description.....	4
1.1. PROGRAM OVERVIEW	4
1.2. PROGRAM PLAN	7
1.3. SCHEDULE, MILESTONES AND DELIVERABLES.....	9
2. Award Information.....	10
3. Eligibility Information.....	13
3.1. ELIGIBLE APPLICANTS	13
3.2. COST SHARING/MATCHING.....	14
4. Application and Submission Information.....	14
4.1. ADDRESS TO REQUEST APPLICATION PACKAGE.....	14
4.2. CONTENT AND FORM OF APPLICATION SUBMISSION	15
4.3. FORMATTING CHARACTERISTICS	19
4.4. SUBMISSION DATES AND TIMES	26
4.5. FUNDING RESTRICTIONS	26
5. Application Review Information	27
5.1. EVALUATION CRITERIA	27
5.2. REVIEW AND SELECTION PROCESS	27
6. Award Administration Information.....	28
6.1. SELECTION NOTICES.....	28
6.2. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS.....	28
6.3. REPORTING.....	33
6.4. ELECTRONIC SYSTEMS.....	33
7. Agency Contacts.....	34
8. Other Information	34
8.1. INTELLECTUAL PROPERTY	34

PART I: OVERVIEW INFORMATION

- **Federal Agency Name** – Defense Advanced Research Projects Agency (DARPA), Biological Technologies Office
- **Funding Opportunity Title** – Targeted Neuroplasticity Training (TNT)
- **Announcement Type** – Initial Announcement
- **Funding Opportunity Number** – DARPA-BAA-16-24
- **Catalog of Federal Domestic Assistance Numbers (CFDA)** - 12.910 Research and Technology Development
- **Dates**
 - **Posting Date:** April 1, 2016
 - **Proposal Due Date:** June 2, 2016, 4:00 PM ET
 - **Proposers' Day:** April 8, 2016
- <https://www.fbo.gov/spg/ODA/DARPA/CMO/DARPA-SN-16-20/listing.html>
- **Concise description of the funding opportunity** – DARPA seeks innovative proposals to develop technology for enhancing cognitive skill learning in healthy adults by using noninvasive peripheral neurostimulation to promote synaptic plasticity in the brain. The Targeted Neuroplasticity Training (TNT) program will elucidate the anatomical and functional map of the underlying neural circuitry involved in regulating synaptic plasticity. The program seeks to demonstrate peripheral modulation of the neural circuit, connect neuroplasticity with cognitive improvements, and optimize intervention protocols for long term retention with no side effects.
- **Anticipated individual awards** – Multiple awards are anticipated.
- **Anticipated funding type** – 6.2
- **Types of instruments that may be awarded** - Procurement contracts, cooperative agreements, and other transactions are the preferred instrument types, though grants may be awarded at the Contracting Officer's discretion.
- **Any cost sharing requirements** – None
- **Agency contact**
 - Dr. Douglas Weber, Program Manager
 - BAA Coordinator: DARPA-BAA-16-24@darpa.mil
 - DARPA/BTO

 - ATTN: DARPA-BAA-16-24
 - 675 North Randolph Street
 - Arlington, VA 22203-2114

PART II: FULL TEXT OF ANNOUNCEMENT

1. Funding Opportunity Description

The Defense Advanced Research Projects Agency (DARPA) often selects its research efforts through the Broad Agency Announcement (BAA) process. This BAA is being issued, and any resultant selection will be made, using procedures under Federal Acquisition Regulation (FAR) 35.016 and the Department of Defense Grant and Agreement Regulatory System (DoDGARS) Part 22 for Grants and Cooperative Agreements. Any negotiations and/or awards will use procedures under FAR 15.4, Contract Pricing, as specified in the BAA (including DoDGARS Part 22 for Grants and Cooperative Agreements). Proposals received as a result of this BAA shall be evaluated in accordance with evaluation criteria specified herein through a scientific review process. DARPA BAAs are posted on the Federal Business Opportunities (FedBizOpps) website, <https://www.fbo.gov/>, and, as applicable, the Grants.gov website at <http://www.grants.gov/>. The following information is for those wishing to respond to the BAA.

Service members are required to learn a variety of specialized skills that require sharp perceptual acuity, rapid and accurate judgment, and effective planning and execution of complex actions. Many of these skills, such as understanding and speaking a new foreign language, can be challenging to learn. Current training programs are time consuming, require intense study, and usually involve a minimum aptitude for eligibility. Thus, improving cognitive skill learning in healthy adults is of great interest to our national security. To address this challenge, DARPA is pursuing the advancement of technology to enhance learning through an approach called Targeted Neuroplasticity Training (TNT), which uses peripheral neurostimulation to selectively promote synaptic plasticity in the brain. TNT will develop a platform technology to enhance learning of a wide range of cognitive skills.

The DARPA TNT program seeks innovative proposals to combine noninvasive peripheral neurostimulation with training paradigms to modulate neuroplasticity for enhancing cognitive skill learning in healthy adults. To develop this capability, the TNT program will focus on identifying and understanding the function of peripheral neurostimulation on the central nervous system circuits that regulate plasticity in the brain. This knowledge will guide selection of peripheral nerve target sites and stimulation parameters to yield maximal learning enhancement while minimizing side effects.

1.1. PROGRAM OVERVIEW

The human brain is capable of integrating intricate and diverse inputs from multiple sensory systems simultaneously in order to rapidly comprehend and assess the information for planning and execution of complex actions. These and other cognitive functions are performed by the vastly interconnected neural networks formed by the roughly 100 billion neurons of the brain. The precise patterns of connectivity among neurons within these networks determines their function, and through experience, these connectivity patterns change over time to enable acquisition of new skills. Indeed, one of the most impressive aspects of brain function is the ability to learn new cognitive skills, such as the ability to understand and speak a foreign language. During learning,

connections between neurons change through a process known as synaptic plasticity, which plays a pivotal role in learning.

While traditional learning brings about changes in neural networks through experience, synaptic plasticity can also be enhanced by activating neuromodulatory regions in the brain via peripheral neurostimulation. This program seeks to use peripheral neurostimulation to facilitate the release of neurotransmitters associated with components of learning, such as acetylcholine, dopamine, serotonin, and norepinephrine. By combining peripheral neurostimulation with conventional training practices, we can leverage endogenous neuronal circuitry to enhance learning by accelerating the tuning of neural networks responsible for cognitive functions.

Recent success with this approach has been demonstrated in clinical rehabilitation studies, utilizing peripheral neurostimulation delivered through implanted electrodes. However, while invasive approaches may be justified for treating people with medical conditions, noninvasive methods are preferred for use in healthy individuals. The TNT program is specifically focused on using noninvasive peripheral neurostimulation to enhance learning in healthy individuals. While the physiological mechanisms underlying noninvasive peripheral neurostimulation and downstream effects on central nervous system (CNS) activity are not well understood, clinical trials have demonstrated modest benefits with noninvasive peripheral neurostimulation as a treatment for epilepsy, depression, anxiety, tinnitus, and pain.

The TNT program will explore and develop peripheral neurostimulation methods and noninvasive devices that boost learning by promoting synaptic plasticity in the brain. Since synaptic plasticity is a universal learning mechanism, it is anticipated that the targeted neuroplasticity intervention will be broadly applicable to a variety of cognitive skills.

1.1.1. Objectives

The research objectives of the TNT program are as follows: 1) elucidate the anatomical and functional map(s) of the peripheral and central nervous system circuitry that regulates synaptic plasticity in the brain; 2) demonstrate effects of peripheral neurostimulation on cognitive skills and the brain activity supporting those skills; and 3) optimize noninvasive stimulation methods and training protocols for long-term retention without negative side effects.

1.1.2. Scope

To develop capabilities for enhancing plasticity and cognitive skill learning, research in the TNT program will focus on two Technical Areas (TA): TA1) Biological Foundations for Targeted Neuroplasticity Training; and TA2) Targeted Neuroplasticity Training Applications for Humans. Integration of both TAs is essential to achieve the program's goal of creating human-ready systems.

Proposers are required to respond to both technical areas in full.

Cognition encompasses a broad range of brain functions. Cognitive skills of interest to TNT include, but are not limited to, sensory perception, comprehension, decision-making, motor intent. Work aimed at enhancing general memory functions is out of scope.

Proposers are expected to address multiple cognitive skills and are encouraged to tie proposed skills to specific Department of Defense (DoD) use cases, such as foreign language learning, intelligence analysis, tactical operation center control, and cryptography. Proposers should incorporate standardized training protocols and evaluation metrics when possible, and proposers should strive for consistency across TA1 and TA2 studies. Proposers should address how proposed tasks relate to the real-world tasks within specific DoD use cases. Specifically, proposers should assess the similarity between proposed task and real-world task environment, stimuli, and response mechanisms. By the end of the program, performers will be expected to demonstrate that the proposed targeted neuroplasticity training applications yield learning rates and/or skill performance that are at least 30% greater than a control group without peripheral neurostimulation.

Proposers should develop research plans that measure learning-induced neurophysiological changes in brain areas that support perception, comprehension, decision-making, and motor control. Behavioral experiments should be designed to directly and quantitatively assess improvements in each of these cognitive skills during learning tasks and to quantify the effects of peripheral neurostimulation on learning rates. Specific peripheral neurostimulation site(s) should be identified along with the known or hypothesized effects on neuromodulatory circuits in the brain. The TNT program is only interested in approaches based on peripheral neurostimulation, excluding all forms of transcranial stimulation (e.g., tDCS, tACS, tRNS, TMS, etc.).

Potential side effects should be identified within the proposal. Proposers should include research plans to assess and mitigate these side effects within the program

In Technical Area 1 (TA1), teams will perform hypothesis-driven research to measure and demonstrate effects of peripheral neurostimulation in promoting plasticity, and assess quantitative changes in neurophysiology and behavior. Established behaving animal models should be used to precisely determine how neurostimulation influences learning and how changes in neural activity affect cognitive functions. DARPA encourages studies that will record activity in large neural populations at single neuron resolution across multiple brain regions simultaneously for extended periods of time. The role of peripheral neurostimulation in promoting plasticity should be validated, such as through the use of neurochemical sensors to measure local neuromodulatory chemical release *in vivo*. The changes in neural activity as they relate to induced neuroplasticity and behavior should be assessed, such as through the analysis and modeling of local neural-network function. Such rigorous and comprehensive studies of brain activity are necessary to understand the effects of peripheral neurostimulation in promoting neuroplasticity and to fully explore the large parameter space for delivering stimulation. This knowledge will guide the selection of optimal peripheral target sites and stimulation parameters for promoting neuroplasticity with minimal negative side effects.

In Technical Area 2 (TA2), teams will develop, demonstrate, and validate cognitive-skill training applications for humans that leverage noninvasive peripheral neurostimulation to promote synaptic plasticity. Experiments and training methods should be designed to address each of the proposed cognitive skills to achieve a thorough understanding of the effects of targeted neuroplasticity training on these basic processes. Functional neuroimaging and/or electrophysiology may be used to measure the location and extent of changes in brain activity during training, with and without neurostimulation. When relevant clinical populations are readily available, DARPA encourages

investigators to test and compare effects of stimulation delivered via implanted and non-implanted electrodes.

It is expected that TA1-2 teams will be multidisciplinary, spanning backgrounds such as cognitive neuroscience, neural plasticity, electrophysiology, systems neurophysiology, biomedical engineering, human performance, and computational modeling. Proposer teams are strongly encouraged to include expertise across these fields, as well as with industry partners that can develop commercial applications based on outputs of the TNT program. The breadth and depth of relevant expertise in the technical team will be an important consideration in the evaluation of proposals.

1.1.3. General Requirements

Performers are expected to attend annual program reviews to provide scientific and technical updates on progress towards their milestones and scientific goals, and to summarize outstanding challenges and limitations that must still be overcome to achieve the overarching TNT goals.

1.2. PROGRAM PLAN

TNT is a four year program comprising two 24-month phases. A detailed description of the research objectives for TAs 1 and 2 are provided in the following two subsections. Section 1.3 outlines the expected schedule, and major milestones and deliverables for the program. Proposals must provide a clear and detailed technical plan with schedule, associated scientific/technical approaches, and risk mitigation plan.

1.2.1. Technical Area 1 (TA1): Biological Foundations for Targeted Neuroplasticity Training.

TA1 Phase I Goals

Proposals should clearly describe plans to assess various peripheral neurostimulation parameters and their efficacy at modulating plasticity and learning rates, evaluated by examining changes in neurophysiology and behavior. Experiments should systematically explore the peripheral neurostimulation parameter space to generate a detailed input/output (I/O) mapping that links stimulation parameters to changes in plasticity. Short-term (e.g., acute) neurophysiological studies in the peripheral and/or central nervous systems are acceptable in Phase I, but chronic recording studies are required in Phase II to permit longer-term studies of learning-induced changes in brain function.

Behavioral tasks and learning paradigms should be chosen to allow direct and quantitative measures of the relevant cognitive skills. By the end of Phase I, teams are expected to demonstrate that their targeted neuroplasticity training methods yield at least a 15% increase in learning rates and/or skill performance relative to a control group without stimulation. Proposers should identify side-effects of peripheral neurostimulation and targeted neuroplasticity training within Phase I.

TA1 Phase II Goals

Phase II of TA1 will focus on optimizing targeted neuroplasticity training methods to reduce or eliminate negative side effects, increasing reproducibility, and ensuring long-term retention.

The peripheral neurostimulation parameters investigated in Phase I should be refined based on the biological understanding and acute cognitive improvements obtained to maximize efficacy of the targeted neuroplasticity training protocol. By the end of Phase II, teams are expected to demonstrate that their targeted neuroplasticity training methods yield at least a 30% increase in cognitive skill acquisition rate relative to control. Chronic studies of neural circuit activity should establish a direct link between stimulation-induced plasticity and changes in circuit function that develop over several days or weeks of training. Proposals should outline methods to assess the longevity of these benefits and determine to what extent and at what rate decay occurs. Teams should optimize peripheral neurostimulation parameters and protocols to maximize efficacy and minimize side effects by the end of Phase II.

1.2.2. Technical Area 2 (TA2): Targeted Neuroplasticity Training Applications for Humans.

TA2 Phase I Goals

The goal of TA2 Phase I is to develop and demonstrate an initial set of targeted neuroplasticity training applications for humans using noninvasive peripheral neurostimulation to promote plasticity. Work in Phase I should validate specific peripheral nerve targets, explore the stimulation parameter space to develop stimulation protocols that are effective, and develop training protocols that pair neurostimulation with training cues to enhance learning.

Proposers are encouraged to measure the effects of peripheral neurostimulation on activity in neuromodulatory regions of the brain that promote plasticity. These studies should aim to verify the physiological effects of peripheral neurostimulation and determine how those effects change with varying stimulation parameters. Appropriate methods should be used to measure the location and extent of changes in relevant brain areas during cognitive skill training, with and without peripheral neurostimulation. Results from the human neurophysiology studies should be compared to the results from TA1 animal studies to verify the mechanisms of the targeted neuroplasticity intervention in humans.

Proposers are encouraged to identify methods for ensuring consistent and accurate placement of electrodes for peripheral neurostimulation. These methods should include measures of one or more physiological responses to peripheral neurostimulation that confirm activation of the intended nerve target. Proposers should also develop plans to identify side effects.

TA2 Phase II goals

The goal of TA2 Phase II will be to verify the efficacy of the targeted neuroplasticity intervention in a randomized controlled study that measures benefits against an unstimulated control group of healthy adult humans. Based on results obtained in Phase I, targeted neuroplasticity intervention protocols should be modified as needed to optimize peripheral neurostimulation parameters for maximum efficacy while minimizing off-target effects. As a target, proposers should aim to achieve at least a 30% increase in learning rate and/or skill performance with targeted neuroplasticity training methods.

To facilitate use of targeted neuroplasticity interventions by non-experts (e.g., at training centers or as a take-home system), the neurostimulation device and interface need to be intuitive, reliable and

safe. Physiological measures that confirm engagement of the intended peripheral nerve should be considered to ensure accurate and reliable positioning of the peripheral neurostimulation device.

1.3. SCHEDULE, MILESTONES AND DELIVERABLES

The research plan for each technical area will be divided into two 24-month phases. The tables below highlight the major research objectives, milestones, and deliverables that are expected during each phase. Proposers should list and describe additional milestones and deliverables that are specific to their planned studies. Proposals should provide specific milestones and quantitative metrics for evaluating progress towards achieving those milestones. DARPA requires proposers to identify intermediate milestones (e.g., at ~6 month intervals) to facilitate tracking of scientific and technical progress. ***Proposals that do not include quantitative metrics, intermediate and end-of-program-phase milestones will be considered non-responsive to the solicitation.***

TNT projects will require animal and human subjects research, and will therefore be subject to both local (i.e. Institutional Animal Care and Use Committee, Institutional Review Board) and DoD-level regulation. Proposers should allow sufficient time in their schedule to obtain the necessary approvals. In general, proposers should expect ~90 days to achieve DoD-level approval after local approval has been awarded.

Table 1: Major Research Objectives, Milestones, and Deliverables for TA1

Phase	Research Objectives	Milestones and Deliverables
I	Demonstrate that peripheral neurostimulation promotes synaptic plasticity by measuring changes in neural activity and neurochemicals in brain.	Provide data validating proposed hypotheses regarding functional and anatomical map(s) of circuitry between peripheral nerve and CNS structures. Input/output response profiles for peripheral neurostimulation and plasticity modulation in CNS.
I	Demonstrate acute effects of targeted neuroplasticity training on brain neurophysiology and learning rate and/or skill performance at least 15% greater than control.	Provide data demonstrating quantified changes in task performance (e.g., accuracy, speed) and neural network physiology (e.g., neural tuning functions and functional connectivity) with training.
I	Test for off-target effects of peripheral neurostimulation and training.	Provide stimulation parameter map for identified side effects.
II	Demonstrate chronic effects of targeted neuroplasticity training on neurophysiology and learning rate and/or skill performance at least 30% greater than control, including measures of long-term retention of trained skills.	Provide data demonstrating quantified changes in task performance (e.g., accuracy, speed) and neural network physiology (e.g., neural tuning functions and functional connectivity) over training periods that span days or weeks and retention evaluated >30 days after training.

Phase	Research Objectives	Milestones and Deliverables
II	Optimization of stimulus protocols in animal models to minimize negative side effects.	A peripheral neurostimulation and training protocol that exhibits minimal side effects in animal models.

Table 2: Major Research Objectives, Milestones, and Deliverables for TA2

Phase	Research Objectives	Milestones and Deliverables
I	Identify mechanisms for modulating neuroplasticity in humans with noninvasive peripheral neurostimulation devices.	Provide data validating proposed hypotheses regarding specific peripheral nerve targets for stimulation and effects on synaptic plasticity, brain function, and learning rates.
II	Refine peripheral neurostimulation and training protocols to ensure easy and reliable operation with minimal negative side effects.	A peripheral neurostimulation device and training protocol with reliable indicators of target nerve engagement and empirical data demonstrating minimal side effects on physical and cognitive functions.
II	Evaluate benefits of targeted neuroplasticity training with goal of demonstrating learning rate and/or skill performance at least 30% above control.	Provide performance data from randomized, controlled study comparing learning rates and retention between targeted neuroplasticity training and unstimulated controls.

Ethical, Legal, and Societal Implications

DARPA is committed to ensuring that efforts funded under this BAA adhere to ethical and legal regulations currently in place for federally- and DoD-funded research involving human and animal use. Proposers to this BAA should address potential ethical, legal, and societal implications of the proposed technology. Please see section [6.2.2](#). (Human Subjects Research).

Data Sharing

All performers funded by the DARPA TNT program shall participate in data sharing with other program performers. Data sharing will be conducted in a manner that provides enough description for a third party to look at and conduct appropriate analysis and interpretation of the data. This data sharing includes, but is not limited to, raw and processed experimental data, processing methods used, algorithms used to process the data, artifact information, research reports, and software including source code and executables.

2. Award Information

Multiple awards are possible. The amount of resources made available under this BAA will depend on the quality of the proposals received and the availability of funds.

The Government reserves the right to select for negotiation all, some, one, or none of the proposals received in response to this solicitation, and to make awards without discussions with

proposers. The Government also reserves the right to conduct discussions if it is later determined to be necessary. If warranted, portions of resulting awards may be segregated into pre-priced options. Additionally, DARPA reserves the right to accept proposals in their entirety or to select only portions of proposals for award. In the event that DARPA desires to award only portions of a proposal, negotiations may be opened with that proposer. The Government reserves the right to fund proposals in phases with options for continued work at the end of one or more of the phases.

Awards under this BAA will be made to proposers on the basis of the evaluation criteria listed below (see section labeled “Application Review Information”, Sec. 5.), and program balance to provide overall value to the Government. The Government reserves the right to request any additional, necessary documentation once it makes the award instrument determination. Such additional information may include but is not limited to Representations and Certifications. The Government reserves the right to remove proposers from award consideration should the parties fail to reach agreement on award terms, conditions and cost/price within a reasonable time or the proposer fails to timely provide requested additional information. Proposals identified for negotiation may result in a procurement contract, grant, cooperative agreement, or other transaction depending upon the nature of the work proposed, the required degree of interaction between parties, whether or not the research is classified as Fundamental Research, and other factors. Procurement contracts, cooperative agreements, or other transactions are preferred.

In all cases, the Government contracting officer shall have sole discretion to select award instrument type and to negotiate all instrument terms and conditions with selectees. Proposers are advised that if they propose grants or cooperative agreements, DARPA may select other award instruments, as it deems appropriate. DARPA will apply publication or other restrictions, as necessary, if it determines that the research resulting from the proposed effort will present a high likelihood of disclosing performance characteristics of military systems or manufacturing technologies that are unique and critical to defense. Any award resulting from such a determination will include a requirement for DARPA permission before publishing any information or results on the program. For more information on publication restrictions, see the section below on Fundamental Research.

Fundamental Research

It is DoD policy that the publication of products of fundamental research will remain unrestricted to the maximum extent possible. National Security Decision Directive (NSDD) 189 established the national policy for controlling the flow of scientific, technical, and engineering information produced in federally funded fundamental research at colleges, universities, and laboratories. The Directive defines fundamental research as follows:

'Fundamental research' means basic and applied research in science and engineering, the results of which ordinarily are published and shared broadly within the scientific community, as distinguished from proprietary research and from industrial development, design, production, and product utilization, the results of which ordinarily are restricted for proprietary or national security reasons.

As of the date of publication of this BAA, the Government expects that program goals as described herein either cannot be met by proposers intending to perform fundamental research or the proposed research is anticipated to present a high likelihood of disclosing performance characteristics of military systems or manufacturing technologies that are unique and critical to defense. Therefore, the Government anticipates restrictions on the resultant research that will require the contractor to seek DARPA permission before publishing any information or results relative to the program.

Proposers should indicate in their proposal whether they believe the scope of the research included in their proposal is fundamental or not. While proposers should clearly explain the intended results of their research, the Government shall have sole discretion to select award instrument type and to negotiate all instrument terms and conditions with selectees. Appropriate clauses will be included in resultant awards for non-fundamental research to prescribe publication requirements and other restrictions, as appropriate.

For certain research projects, it may be possible that although the research being performed by the prime contractor is restricted research, a subawardee may be conducting fundamental research. In those cases, it is the prime contractor's responsibility to explain in its proposal why its subawardee's effort is fundamental research.

The following statement or similar provision will be incorporated into any resultant non-fundamental research procurement contract or other transaction:

There shall be no dissemination or publication, except within and between the contractor and any subawardees, of information developed under this contract or contained in the reports to be furnished pursuant to this contract without prior written approval of DARPA's Public Release Center (DARPA/PRC). All technical reports will be given proper review by appropriate authority to determine which Distribution Statement is to be applied prior to the initial distribution of these reports by the contractor. With regard to subawardee proposals for Fundamental Research, papers resulting from unclassified fundamental research are exempt from prepublication controls and this review requirement, pursuant to DoD Instruction 5230.27 dated October 6, 1987.

When submitting material for written approval for open publication, the contractor/awardee must submit a request for public release to the DARPA/PRC and include the following information: (1) Document Information: document title, document author, short plain-language description of technology discussed in the material (approx. 30 words), number of pages (or minutes of video) and document type (e.g., briefing, report, abstract, article, or paper); (2) Event Information: event type (conference, principal investigator meeting, article or paper), event date, desired date for DARPA's approval; (3) DARPA Sponsor: DARPA Program Manager, DARPA office, and contract number; and (4) Contractor/Awardee's Information: POC name, email and phone. Allow four weeks for processing; due dates under four weeks require a justification. Unusual electronic file formats may require additional processing time. Requests may be sent either via email to public_release_center@darpa.mil or by mail at 675 North Randolph Street, Arlington VA 22203-2114, telephone (571) 218-4235. Refer to the following for

link for information about DARPA's public release process: <http://www.darpa.mil/work-with-us/contract-management/public-release>."

3. Eligibility Information

All responsible sources capable of satisfying the Government's needs may submit a proposal that shall be considered by DARPA.

3.1. ELIGIBLE APPLICANTS

3.1.1. Federally Funded Research and Development Centers (FFRDCs) and Government Entities

Federally Funded Research and Development Centers (FFRDCs) and Government entities (e.g., Government/National laboratories, military educational institutions, etc.) are subject to applicable direct competition limitations and cannot propose to this BAA in any capacity unless they meet the following conditions: (1) FFRDCs must clearly demonstrate that the proposed work is not otherwise available from the private sector; and (2) FFRDCs must provide a letter on official letterhead from their sponsoring organization citing the specific authority establishing their eligibility to propose to Government solicitations and compete with industry, and their compliance with the associated FFRDC sponsor agreement's terms and conditions. This information is required for FFRDCs proposing to be prime contractors or subawardees. Government entities must clearly demonstrate that the work is not otherwise available from the private sector and provide written documentation citing the specific statutory authority and contractual authority, if relevant, establishing their ability to propose to Government solicitations. At the present time, DARPA does not consider 15 U.S.C. § 3710a to be sufficient legal authority to show eligibility. While 10 U.S.C. § 2539b may be the appropriate statutory starting point for some entities, specific supporting regulatory guidance, together with evidence of agency approval, will still be required to fully establish eligibility. DARPA will consider FFRDC and Government entity eligibility submissions on a case-by-case basis; however, the burden to prove eligibility for all team members rests solely with the proposer.

3.1.2. Non-U.S. Organizations

Non-U.S. organizations are/or individuals may participate to the extent that such participants comply with any necessary nondisclosure agreements, security regulations, export control laws, and other governing statutes applicable under the circumstances. See Section 4.2 "Security and Proprietary Issues" regarding the proposers capabilities to perform research and development at the classification level they propose.

3.1.3. Procurement Integrity, Standards of Conduct, Ethical Considerations, and Organizational Conflicts of Interest

Current federal employees are prohibited from participating in particular matters involving conflicting financial, employment, and representational interests (18 U.S.C. §§ 203, 205, and 208). Once the proposals have been received, and prior to the start of proposal evaluations, the Government will assess potential conflicts of interest and will promptly notify the proposer if any

appear to exist. The Government assessment does NOT affect, offset, or mitigate the proposer's responsibility to give full notice and planned mitigation for all potential organizational conflicts, as discussed below.

Without prior approval or a waiver from the DARPA Director, in accordance with FAR 9.503, a contractor cannot simultaneously provide scientific, engineering, technical assistance (SETA) or similar support and also be a technical performer. As part of the proposal submission, all members of the proposed team (prime proposers, proposed subawardees, and consultants) must affirm whether they (their organizations and individual team members) are providing SETA or similar support to any DARPA technical office(s) through an active contract or subcontract. All affirmations must state which office(s) the proposer, subawardees, consultant, or individual supports and identify the prime contract number(s). All facts relevant to the existence or potential existence of organizational conflicts of interest (FAR 9.5) must be disclosed. The disclosure must include a description of the action the proposer has taken or proposes to take to avoid, neutralize, or mitigate such conflict. If in the sole opinion of the Government after full consideration of the circumstances, a proposal fails to fully disclose potential conflicts of interest and/or any identified conflict situation cannot be effectively mitigated, the proposal will be rejected without technical evaluation and withdrawn from further consideration for award.

If a prospective proposer believes a conflict of interest exists or may exist (whether organizational or otherwise) or has questions on what constitutes a conflict of interest, the proposer should send his/her contact information and a summary of the potential conflict via email to the BAA email address before time and effort are expended in preparing a proposal and mitigation plan.

3.2. COST SHARING/MATCHING

Cost-sharing proposals are encouraged, but not required. Information about cost-sharing can be found here: <http://www.darpa.mil/work-with-us/contract-management>

While cost sharing is not required it will be carefully considered where there is an applicable statutory condition relating to the selected funding instrument (e.g., for any Other Transactions under the authority of 10 U.S.C. § 2371). Cost sharing is encouraged where there is a reasonable probability of a potential commercial application related to the proposed research and development effort.

4. Application and Submission Information

4.1. ADDRESS TO REQUEST APPLICATION PACKAGE

This solicitation contains all information required to submit a proposal. No additional forms, kits, or other materials are needed. This notice, with the classified addendum, constitutes the total solicitation. No additional information is available, except as provided at FBO.gov or Grants.gov, nor will a formal Request for Proposal (RFP) or additional solicitation regarding this announcement be issued. Requests for the same will be disregarded.

4.2. CONTENT AND FORM OF APPLICATION SUBMISSION

4.2.1. Proprietary and Security Information

DARPA policy is to treat all submissions as source selection information (see FAR 2.101 and 3.104), and to disclose their contents only for the purpose of evaluation. Restrictive notices notwithstanding, during the evaluation process, submissions may be handled by support contractors for administrative purposes and/or to assist with technical evaluation. All DARPA support contractors performing this role are expressly prohibited from performing DARPA-sponsored technical research and are bound by appropriate nondisclosure agreements.

Submissions will not be returned. The original of each submission received will be retained at DARPA and all other non-required copies destroyed. A certification of destruction may be requested, provided the formal request is received at this office within 5 days after notification that a proposal was not selected.

4.2.1.1 Proprietary Information

Proposers are responsible for clearly identifying proprietary information. Submissions containing proprietary information must have the cover page and each page containing such information clearly marked with a label such as “Proprietary” or “Company Proprietary.” Note, “Confidential” is a classification marking used to control the dissemination of U.S. Government National Security Information as dictated in Executive Order 13526 and should not be used to identify proprietary business information.

4.2.1.2 Security Information

Classified submissions shall be transmitted in accordance with the following guidance. Additional information on the subjects discussed in this section may be found at <http://www.dss.mil/>.

If a submission contains Classified National Security Information as defined by Executive Order 13526, the information must be appropriately and conspicuously marked with the proposed classification level and declassification date. Similarly, when the classification of a submission is in question, the submission must be appropriately and conspicuously marked with the proposed classification level and declassification date. Submissions requiring DARPA to make a final classification determination shall be marked as follows:

“CLASSIFICATION DETERMINATION PENDING. Protect as though classified (insert the recommended classification level, e.g., Top Secret, Secret or Confidential)”

NOTE: Classified submissions must indicate the classification level of not only the submitted materials, but also the classification level of the anticipated award.

Proposers submitting classified information must have, or be able to obtain prior to contract award, cognizant security agency approved facilities, information systems, and appropriately

cleared/eligible personnel to perform at the classification level proposed. All proposer personnel performing Information Assurance (IA)/Cybersecurity related duties on classified Information Systems shall meet the requirements set forth in DoD Manual 8570.01-M (Information Assurance Workforce Improvement Program).

Proposers choosing to submit classified information from other collateral classified sources (i.e., sources other than DARPA) must ensure (1) they have permission from an authorized individual at the cognizant Government agency (e.g., Contracting Officer, Program Manager); (2) the proposal is marked in accordance with the source Security Classification Guide (SCG) from which the material is derived; and (3) the source SCG is submitted along with the proposal.

DARPA anticipates that submissions received under this BAA will be unclassified. However, should a proposer wish to submit classified information, an *unclassified* email must be sent to the BAA mailbox requesting submission instructions from the Technical Office PSO.

Security classification guidance and direction via a Security Classification Guide (SCG) and/or DD Form 254, “DoD Contract Security Classification Specification,” will not be provided at this time, since DARPA is soliciting ideas only. If a determination is made that the award instrument may result in access to classified information, a SCG and/or DD Form 254 will be issued by DARPA and attached as part of the award.

4.2.2. Submission Information

The typical proposal should express a consolidated effort in support of one or more related technical concepts or ideas. Disjointed efforts should not be included into a single proposal.

Restrictive notices notwithstanding, proposals may be handled, for administrative purposes only, by a support contractor. This support contractor is prohibited from competition in DARPA technical research and is bound by appropriate nondisclosure requirements.

Proposals not meeting the format described in the BAA may not be reviewed.

For Proposers Submitting Full Proposals through DARPA’s BAA Submission Portal:

Full Proposals sent in response to DARPA-BAA-16-24 may be submitted via DARPA’s BAA Website (<https://baa.darpa.mil>). Visit the website to complete the two-step registration process. Submitters will need to register for an Extranet account (via the form at the URL listed above) and wait for two separate e-mails containing a username and temporary password. After accessing the Extranet, submitters may then create an account for the DARPA BAA website (via the “Register your Organization” link along the left side of the homepage), view submission instructions, and upload/finalize the abstract. Proposers using the DARPA BAA Website may encounter heavy traffic on the submission deadline date; it is highly advised that submission process be started as early as possible.

All unclassified concepts submitted electronically through DARPA’s BAA Website must be uploaded as zip files (.zip or .zipx extension). The final zip file should be no greater than 50 MB

in size. Only one zip file will be accepted per submission. Classified submissions and proposals requesting assistance instruments (grants or cooperative agreements) should NOT be submitted through DARPA's BAA Website (<https://baa.darpa.mil>), though proposers will likely still need to visit <https://baa.darpa.mil> to register their organization (or verify an existing registration) to ensure the BAA office can verify and finalize their submission.

Technical support for BAA Website may be reached at BAAT_Support@darpa.mil, and is typically available during regular business hours, (9:00 AM- 5:00 PM EST Monday – Friday).

Proposers using the DARPA BAA Website may encounter heavy traffic on the submission deadline date; it is highly advised that submission process be started as early as possible.

For Proposers Requesting Grants or Cooperative Agreements:

Proposers requesting grants or cooperative agreements may submit proposals through one of the following methods: (1) hard copy mailed directly to DARPA; or (2) electronic upload per the instructions at <http://www.grants.gov/applicants/apply-for-grants.html>. Grant or cooperative agreement proposals may not be submitted through any other means. If proposers intend to use Grants.gov as their means of submission, then they must submit their entire proposal through Grants.gov; applications cannot be submitted in part to Grants.gov and in part as a hard-copy. Proposers using the Grants.gov do not submit paper proposals in addition to the Grants.gov electronic submission.

Grants.gov requires proposers to complete a one-time registration process before a proposal can be electronically submitted. If proposers have not previously registered, this process can take between three business days and four weeks. See the Grants.gov registration checklist at <http://www.grants.gov/documents/19/18243/OrganizationRegChecklist.pdf> for registration requirements and instructions.

Once Grants.gov has received a proposal submission, Grants.gov will send two email messages to advise proposers as to whether or not their proposals have been validated or rejected by the system; IT MAY TAKE UP TO TWO DAYS TO RECEIVE THESE EMAILS. The first email will confirm receipt of the proposal by the Grants.gov system; this email only confirms receipt, not acceptance, of the proposal. The second will indicate that the application has been successfully validated by the system prior to transmission to the grantor agency or has been rejected due to errors. If the proposal is validated, then the proposer has successfully submitted their proposal. If the proposal is rejected, the proposed must be corrected and resubmitted before DARPA can retrieve it. If the solicitation is no longer open, the rejected proposal cannot be resubmitted. Once the proposal is retrieved by DARPA, the proposer will receive a third email from Grants.gov. To avoid missing deadlines, proposers should submit their proposals in advance of the final proposal due date with sufficient time to receive confirmations and correct any errors in the submission process through Grants.gov. For more information on submitting proposals to Grants.gov, visit the Grants.gov submissions page at: <http://www.grants.gov/web/grants/applicants/apply-for-grants.html>

Upload two separate documents, Volume I, Technical and Management Proposal and Volume II, the Cost Proposal as attachments to the application package. **No other Grants.gov forms are required.** Please note that Grants.gov does not accept zipped or encrypted proposals. More detailed instructions for using Grants.gov can be found on the Grants.gov website.

Proposers electing to submit grant or cooperative agreement proposals as hard copies must complete the SF 424 R&R form (Application for Federal Assistance, Research and Related) available on the Grants.gov website http://apply07.grants.gov/apply/forms/sample/RR_SF424_2_0-V2.0.pdf. Technical support for Grants.gov submissions may be reached at 1-800-518-4726 or support@grants.gov.

Please note that submitters to Grants.gov will still need to visit <https://baa.darpa.mil> to register their organization concurrently to ensure the BAA office can verify and finalize their submission.

All administrative correspondence and questions on this solicitation, including requests for information on how to submit a proposal to this BAA, should be directed to one of the administrative addresses below; e-mail is preferred.

BAA Administrator

E-mail: DARPA-BAA-16-24@darpa.mil

DARPA/BTO

ATTN: DARPA-BAA-16-24

675 North Randolph Street

Arlington, VA 22203-2114

Office Website: <http://www.darpa.mil/about-us/offices/bto>

Solicitations Page: <http://www.darpa.mil/work-with-us/opportunities>

DARPA intends to use electronic mail for correspondence regarding DARPA-BAA-16-24. Proposals may not be submitted by fax or e-mail; any so sent will be disregarded. DARPA encourages use of the Internet for retrieving the BAA and any other related information that may subsequently be provided.

4.2.3. Restrictive Markings on Proposals

All proposals should clearly indicate limitations on the disclosure of their contents. Proposers who include in their proposals data that they do not want disclosed to the public for any purpose, or used by the Government except for evaluation purposes, shall-

(1) Mark the title page with the following legend:

This proposal includes data that shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed-in whole or in part-for any purpose other than to evaluate this proposal. If, however, a contract is awarded to this proposer as a result of, or in connection with, the submission of this data, the Government shall have the right to duplicate, use, or disclose the data to the extent provided in the resulting contract. This restriction does not limit the

Government's right to use information contained in this data if it is obtained from another source without restriction. The data subject to this restriction are contained in sheets [insert numbers or other identification of sheets]; and

(2) Mark each sheet of data it wishes to restrict with the following legend:

“Use or disclosure of data contained on this sheet is subject to the restriction on the title page of this proposal.”

Markings like "Company Confidential" or other phrases that may be confused with national security classifications shall be avoided.

4.3. FORMATTING CHARACTERISTICS

4.3.1. Proposal Format

NOTE (classification and handling markings): Confidential, Secret and Top Secret are classification markings used to control the dissemination of US Government National Security Information (NSI) as dictated in Executive Order 13526 - "Classified National Security Information". When referencing business proprietary information in a response to this BAA, please refrain from using any combination of the NSI caveats unless the content is classified.

Proposers are limited to only 1 full proposal submission addressing both TA1 and TA2, based on the requirements listed below. **Proposers who submit a proposal that addresses only one TA will be considered non-responsive to the solicitation.** All full proposals must be in the format given below. Nonconforming proposals may be rejected without review. Proposals shall consist of two volumes. All pages shall be printed on 8-1/2 by 11 inch paper with type not smaller than 12 point. Smaller font may be used for figures, tables and charts. The page limitation for full proposals includes all figures, tables, and charts. Volume I, Technical and Management Proposal, may include an attached bibliography of relevant technical papers or research notes (published and unpublished) which document the technical ideas and approach upon which the proposal is based. The Bibliography, Key References, Bio-sketches, and Letters of Support (optional) are not included in the page counts given below. The submission of other supporting materials along with the proposals is strongly discouraged and will not be considered for review. **Proposers must adhere to page count limitations for the sections indicated below.** A submission letter is required and is not included in the page count. Volume I should include the following components:

a. Volume I, Technical and Management Proposal

Section I. Administrative

A. Cover Sheet (LABELED “PROPOSAL: VOLUME I”):

1. BAA number (DARPA-BAA-16-24);
2. Technical area;
3. Lead organization (prime contractor);

4. Type of organization, selected from among the following categories: “LARGE BUSINESS,” “SMALL DISADVANTAGED BUSINESS,” “OTHER SMALL BUSINESS,” “HBCU,” “MI,” “OTHER EDUCATIONAL,” OR “OTHER NONPROFIT”;
5. Proposer’s reference number (if any);
6. Other team members (if applicable) and type of business for each;
7. Proposal title;
8. Technical point of contact (Program Manager or Principle Investigator) to include: salutation, last name, first name, street address, city, state, zip code, telephone, fax, e-mail;
9. Contracting Officer or Grant Officer to include: salutation, last name, first name, street address, city, state, zip code, telephone, fax, e-mail;
10. Award instrument requested: cost-plus-fixed-fee (CPFF), cost-award—no fee, firm-fixed-price, grant, cooperative agreement, other transaction, or other type (specify);
11. Place(s) and period(s) of performance ;
12. Proposal validity period;
13. DUNS number (<http://www.dnb.com/get-a-duns-number.html>);
14. Taxpayer ID number (<https://www.irs.gov/Individuals/International-Taxpayers/Taxpayer-Identification-Numbers-TIN>);
15. CAGE code (<https://www.dlis.dla.mil/bincs/FAQ.aspx>);

Information on award instruments is available at <http://www.darpa.mil/work-with-us/contract-management>.

B. Official Transmittal Letter.

Section II. Detailed Proposal Information

A. Executive summary (Maximum 3 pages):

Summary of innovative claims for the proposed research. This section should succinctly describe the uniqueness and benefits of the proposed approach relative to the current state-of-art alternate approaches. Clearly describe the scientific and technical goals, challenges, approach, key innovations, and expected impact of the proposed effort. Articulate your objectives without jargon. Include answers to the following questions:

- a. What are you proposing to do? What is the expected outcome?
- b. What is innovative in your approach? How is your approach better than the current state-of-the-art, alternative approaches, and previous efforts? Be quantitative. Why do you think your approach will succeed? Summarize scientific rationale supporting your approach.
- c. What are the risks and payoffs? What are the key technical challenges in your approach and how do you plan to overcome these?
- d. If you are successful, who or what will be affected and what will be the impact? Include expected quantitative and qualitative outcomes in terms of the knowledge revealed or technologies utilized.

- e. How much will it cost, and how long will it take to complete the major tasks? Critically evaluate the expected impact of your work relative to the cost.

B. Scientific/Technical Approach and Plan (Maximum 40 pages):

Detailed scientific/technical rationale and description of the planned approach and execution plan. The technical plan should demonstrate a deep understanding of the scientific challenges and present a credible (even if risky) plan to achieve the program goals. The technical approach should address all applicable proposal content instructions in Sections 1.1 – 1.3. Include comparisons with other ongoing research indicating advantages and disadvantages of the proposed effort. Discuss the proposed research team's previous accomplishments and work in closely related research areas. Proposers should address the state-of-the-art technology and current limitations.

1. **For each primary objective (i.e. task), describe the following:**
 - a. **Goal:** Succinctly describe the task/objective and what will be accomplished if successful.
 - b. **Personnel:** Identify the personnel responsible for the task/objective (e.g. "led by Jane Smith with support from one graduate student at 50% effort").
 - c. **Approach:** Describe the scientific and technical approach. Hypotheses should be articulated clearly and include a rigorous test plan with quantitative metrics to yield unambiguous outcomes. Experimental designs and procedures must be described thoroughly, including aspects such as equipment, behavioral paradigms, animal models, approximate numbers of subjects, software, analysis plan, etc. Figures and diagrams that help illustrate the experimental design may be included.
 - d. **Rationale:** Provide a clear rationale for the approach, including a justification for the feasibility of the proposed task. ***Proposers are highly encouraged to include supporting data when available, even if preliminary.*** Figures included within the proposal should be accompanied by a brief description of how data was collected, what analysis was performed, what the results mean, and why the result supports the feasibility of the proposed task.
 - e. **Schedule:** Include a narrative overview of the timeline of the task/objective. Intermediate milestones and final completion criteria should be identified along with the quantitative metrics that will be used to evaluate progress.
 - f. **Challenges and Risks:** Articulate the scientific and technical challenges and risks facing this effort. Include a risk mitigation plan including possible solutions for overcoming potential hurdles or alternative approaches.
2. **Summary Materials:**
 - a. **Overall Timeline:** Include a one-page high-level graphical (Gantt or flow chart style) timeline of the outlined tasks/objectives described in the Scientific/Technical Approach and Plan.
 - b. **Management Plan:** Include an organization chart for the entire team which includes, as applicable: (1) the programmatic relationship of team member; (2) the unique capabilities of team members; (3) the task responsibilities of team members; (4) the teaming strategy among the team

members; and (5) the key personnel along with the amount of effort to be expended by each person during each year.

- c. **Facilities:** Include a description of the facilities that would be used for the proposed effort. Detail support enhancing that of Section II, including formal teaming agreements which are required to execute this program.

C. Statement of Work (SOW), Milestones, and Deliverables (Does not count towards page limit):

The Government requires proposers to complete an editable MS Word SOW template that covers much of the details discussed below; download and fully-complete the template provided in **Attachment 2** posted with the subject BAA.

The SOW must be read as a stand-alone document without references to text or figures included in Section B. Each Phase of the program should be defined separately. Dependencies between tasks and/or subtasks should be identified clearly. No proprietary information should be included within the document.

Provide the following for each task/subtask:

- a. A general description of the scientific or technical objective of the task/subtask.
- b. A brief but detailed description of the technical approach to be taken to accomplish the task/subtask, including succinct explanation and justification for the chosen methodologies.
- c. Identification of the primary organization responsible for task execution (prime, sub, team member, by name, etc.).
- d. The completion criteria for each task/subtask, i.e. a product, event, deliverable, measurable milestone, or demonstration that defines its completion. Whenever possible, completion should be assessed through quantitative metrics.
- e. Define all deliverables (reporting, data, reports, software, etc.) to be provided to the Government in support of the proposed research tasks/activities.
- f. Estimates of cost for each task/activity in each year of the effort delineated by the primes and major subcontractors, total cost, and any company cost share.
- g. Schedule for all measurable milestones and deliverables should capture key development points in tasks and should be clearly articulated and defined in time relative to start of effort (relative to months after contract start – MAC). The milestones must not include proprietary information.

D. Summary Graphic(s) (Does not count towards page limit):

Power Point slide(s) summarizing the proposed effort's vision, goals, impact, scientific/technical approach, and milestone schedule. Download and use the template provided in **Attachment 3** posted with the subject BAA. Submit the PowerPoint file in addition to Volume I and II of your proposal.

Section III. Additional Information (Does not count towards page limit)

(1) Bibliography (required): list of references cited in the body of the proposal. There is no limit to the number of references that can be cited in this section.

(2) Key References (optional): a brief bibliography of relevant technical papers and research notes (published and unpublished) that are most relevant in supporting the technical ideas of the proposal and/or document the key technical ideas on which the proposal is based. Include no more than 10 publications in your list. This section can include published or unpublished papers and research notes. If a reference is unpublished, please attach it to the proposal.

(3) A resume or “Bio-sketch” of all key personnel; NIH style bio-sketches are preferred.

(4) Letters of Support (optional): Proposers may wish to provide letters of support from key personnel or other collaborators.

4.4.2.2 Volume II, Cost Proposal – {No Page Limit}

All proposers, including FFRDCs, must submit the following:

Cover sheet to include:

1. BAA number;
2. Technical area;
3. Lead Organization Submitting proposal;
4. Type of organization, selected among the following categories: “LARGE BUSINESS”, “SMALL DISADVANTAGED BUSINESS”, “OTHER SMALL BUSINESS”, “HBCU”, “MI”, “OTHER EDUCATIONAL”, OR “OTHER NONPROFIT”;
5. Proposer’s reference number (if any);
6. Other team members (if applicable) and type of business for each;
7. Proposal title;
8. Technical point of contact to include: salutation, last name, first name, street address, city, state, zip code, telephone, fax (if available), electronic mail (if available);
9. Administrative point of contact to include: salutation, last name, first name, street address, city, state, zip code, telephone, fax (if available), and electronic mail (if available);
10. Award instrument requested: cost-plus-fixed-fee (CPFF), cost-contract—no fee, cost sharing contract – no fee, or other type of procurement contract (*specify*), or other transaction;
11. Place(s) and period(s) of performance;
12. Total proposed cost separated by basic award and option(s) (if any);
13. Name, address, and telephone number of the proposer’s cognizant Defense Contract Management Agency (DCMA) administration office (*if known*);
14. Name, address, and telephone number of the proposer’s cognizant Defense Contract Audit Agency (DCAA) audit office (*if known*);
15. Date proposal was prepared;
16. DUNS number (<http://www.dnb.com/get-a-duns-number.html>) ;

17. Taxpayer ID number (<https://www.irs.gov/Individuals/International-Taxpayers/Taxpayer-Identification-Numbers-TIN>);
18. CAGE code (<https://www.dlis.dla.mil/bincs/FAQ.aspx>);
19. Proposal validity period

Note that nonconforming proposals may be rejected without review.

NOTE: **Attachment 1**, the Cost Volume Proposer Checklist, must be included with the coversheet of the Cost Proposal

Proposers without an accounting system considered adequate for determining accurate costs must complete an SF 1408 if a cost type contract is to be negotiated. To facilitate this process, proposers should complete the SF 1408 found at:

<http://www.gsa.gov/portal/forms/download/115778> and submit the completed form with the proposal. To complete the form, check the boxes on the second page, then provide a narrative explanation of your accounting system to supplement the checklist on page one. For more information, please see:

http://www.dcaa.mil/preaward_accounting_system_adequacy_checklist.html.

The Government encourages proposers to complete an editable MS excel budget template that covers items 1.i, 1.iv, 2, 3, 4, and 5 discussed below. This template document is provided as **Attachment 4** to this BAA. If you choose to use **Attachment 4**, submit the MS Excel template in addition to Volume I and II of your proposal. Volume II must include all other items discussed below that are not covered by the editable MS excel budget template. Proposers are welcome to utilize an alternative format, provided the information requested below is clearly and effectively communicated.

- (1) total program cost broken down by major cost items to include:
 - i. direct labor, including individual labor categories or persons, with associated labor hours and numbered direct labor rates
 - ii. If consultants are to be used, proposer must provide consultant agreement or other document which verifies the proposed loaded daily/hourly rate
 - iii. Indirect costs including Fringe Benefits, Overhead, General and Administrative Expense, Cost of Money, etc. (Must show base amount and rate)
 - iv. Travel – Number of trips, number of days per trip, departure and arrival destinations, number of people, etc.
 - v. Other Direct Costs – Should be itemized with costs or estimated costs. Backup documentation will be submitted to support proposed costs. An explanation of any estimating factors, including their derivation and application, must be provided. Please include a brief description of the proposers' procurement method to be used;
- (2) major program tasks by phase;
- (3) an itemization of major subcontracts and equipment purchases, to include: a cost proposal as detailed as the Proposer's cost proposal;
- (4) an itemization of any information technology (IT) purchase, as defined in FAR Part 2.101;
- (5) a summary of projected funding requirements by month;

- (6) the source, nature, and amount of any industry cost-sharing. Where the effort consists of multiple portions which could reasonably be partitioned for purposes of funding, these should be identified as options with separate cost estimates for each; and
- (7) identification of pricing assumptions of which may require incorporation into the resulting award instrument (e.g., use of Government Furnished Property/Facilities/Information, access to Government Subject Matter Expert/s, etc.).

The proposer should include supporting cost and pricing information in sufficient detail to substantiate the summary cost estimates and should include a description of the method used to estimate costs and supporting documentation. Per FAR 15.403-4, certified cost or pricing data shall be required if the proposer is seeking a procurement contract award per the referenced threshold, unless the proposer requests an exception from the requirement to submit cost or pricing data. Certified cost or pricing data are not required if the proposer proposes an award instrument other than a procurement contract (e.g., a grant, cooperative agreement, or Other Transaction.)

The prime proposer is responsible for compiling and providing all subcontractor proposals for the Procuring Contracting Officer (PCO). Subcontractor proposals should include Interdivisional Work Transfer Agreements (ITWA) or similar arrangements. Where the effort consists of multiple portions which could reasonably be partitioned for purposes of funding, these should be identified as options with separate cost estimates for each. NOTE: for IT and equipment purchases, include a letter stating why the proposer cannot provide the requested resources from its own funding.

All proprietary subcontractor proposal documentation, prepared at the same level of detail as that required of the prime. The prime and subcontractor proposals should be uploaded together if possible to DARPA's BAA Website (<https://baa.darpa.mil/>). If the subcontractor proposal contains proprietary information not releasable to the prime, the subcontractor may upload their proposal separately but identify the proposal as a subcontract proposal and provide the name and proposal title of the prime contractor. Subcontractor proposals submitted by hard copy can be submitted in a sealed envelope by the prime or directly by the subcontractor. If submitted directly by the subcontractor the subcontractor must identify the proposal as a subcontract proposal and provide the name and proposal title of the prime proposer. Subcontractors must provide the same number of hard copies and/or electronic proposals as is required of the prime proposer.

All proposers requesting an 845 Other Transaction for Prototypes (OT) agreement must include a detailed list of milestones. Each such milestone must include the following: milestone description, completion criteria, due date, and payment/funding schedule (to include, if cost share is proposed, contractor and Government share amounts). It is noted that, at a minimum, such milestones should relate directly to accomplishment of program technical metrics as defined in the BAA and/or the proposer's proposal. Agreement type, fixed price or expenditure based, will be subject to negotiation by the Agreements Officer; however, it is noted that the Government prefers use of fixed price milestones with a payment/funding schedule to the maximum extent possible. Do not include proprietary data. If the proposer requests award of an 845 OT agreement as a nontraditional defense contractor, as so defined in the OSD guide entitled "Other Transactions (OT) Guide For Prototype Projects" dated January 2001 (as amended) (<http://www.acq.osd.mil/dpap/Docs/otguide.doc>), information must be included in the cost proposal to support the claim. Additionally, if the proposer requests award of an 845 OT

agreement, without the required one-third (1/3) cost share, information must be included in the cost proposal supporting that there is at least one non-traditional defense contractor participating to a significant extent in the proposed prototype project. For information on 845 Other Transaction for Prototypes (OT) agreements, refer to <http://www.darpa.mil/work-with-us/contract-management>.

Per Section 8123 of the Department of Defense Appropriations Act, 2015 (Division C of the Consolidated and Further Continuing Appropriations Act, 2015, Pub. L. 113-235), all grant awards must be posted on a public website in a searchable format. To facilitate this task, proposers requesting grant awards must submit a maximum one (1) page abstract that may be publicly posted to comply with the requirement of Section 8123. This abstract should explain the project or program to the public and should only contain information that the proposer confirms is releasable to the public; **DO NOT INCLUDE ANY PROPRIETARY INFORMATION OR INFORMATION THAT CANNOT BE DISPLAYED ON A PUBLIC WEBSITE**. The proposer should sign the bottom of the abstract confirming the information in the abstract is approved for public release. Proposers are advised to provide both a signed PDF copy, as well as an editable (e.g., Microsoft word) copy. Abstracts contained in grant proposals that are not selected for award will not be publicly posted.

4.4. SUBMISSION DATES AND TIMES

4.4.1. Full Proposal Submission Deadline

The full proposals must be submitted to DARPA/BTO on or before 4:00 PM, Eastern Time, June 2, 2016 in order to be considered during selections. Proposals submitted after the deadline will not be accepted or reviewed. The actual amount of resources available under this BAA will depend on the quality of proposals received and availability of funds.

Failure to comply with the submission procedures may result in the submission not being evaluated. DARPA will acknowledge receipt of complete submissions via email and assign control numbers that should be used in all further correspondence regarding proposals.

DARPA will routinely post consolidated Question and Answer lists in response to any relevant BAA clarification question(s) before final full proposals are due. In order to receive a response to your question, submit your question by May 18, 2016 to DARPA-BAA-16-24@darpa.mil.

4.5. FUNDING RESTRICTIONS

For contracts and Other Transaction Agreements, preaward costs will not be reimbursed unless a preaward cost agreement is negotiated prior to award. For Grants and Cooperative Agreement, preaward costs are permitted to the extent authorized by the DoD Grants and Agreements Regulations (DoDGARs) unless otherwise notified by the Contracting Officer.

5. Application Review Information

5.1. EVALUATION CRITERIA

Proposals will be evaluated using the following criteria, listed in descending order of importance: Overall Scientific and Technical Merit (5.1.1); Potential Contribution and Relevance to the DARPA Mission (5.1.2); Cost Realism (5.1.3).

5.1.1. Overall Scientific and Technical Merit

The proposed technical approach is feasible, achievable, complete and supported by a proposed technical team that has the expertise and experience to accomplish the proposed tasks.

5.1.2. Potential Contribution and Relevance to the DARPA Mission

The potential contributions of the proposed effort are relevant to the national technology base. Specifically, DARPA's mission is to maintain the technological superiority of the U.S. military and prevent technological surprise from harming our national security by sponsoring revolutionary, high-payoff research that bridges the gap between fundamental discoveries and their application.

5.1.3. Cost Realism

The proposed costs are realistic for the technical and management approach and accurately reflect the technical goals and objectives of the solicitation. The proposed costs are consistent with the proposer's Statement of Work and reflect a sufficient understanding of the costs and level of effort needed to successfully accomplish the proposed technical approach. The costs for the prime proposer and proposed subawardees are substantiated by the details provided in the proposal (e.g., the type and number of labor hours proposed per task, the types and quantities of materials, equipment and fabrication costs, travel and any other applicable costs).

It is expected that the effort will leverage all available relevant prior research in order to obtain the maximum benefit from the available funding. For efforts with a likelihood of commercial application, appropriate direct cost sharing may be a positive factor in the evaluation. DARPA recognizes that undue emphasis on cost may motivate proposers to offer low-risk ideas with minimum uncertainty and to staff the effort with junior personnel in order to be in a more competitive posture. DARPA discourages such cost strategies.

5.2. REVIEW AND SELECTION PROCESS

DARPA will conduct a scientific/technical review of each conforming proposal. Proposals will not be evaluated against each other since they are not submitted in accordance with a common work statement. DARPA's intent is to review proposals as soon as possible after they arrive; however, proposals may be reviewed periodically for administrative reasons.

Award(s) will be made to proposers whose proposals are determined to be the most advantageous to the Government, all factors considered, including the potential contributions of the proposed work to the overall research program and the availability of funding for the effort.

It is the policy of DARPA to ensure impartial, equitable, comprehensive proposal evaluations and to select the source (or sources) whose offer meets the Government's technical, policy, and programmatic goals. Pursuant to FAR 35.016, the primary basis for selecting proposals for acceptance shall be technical, importance to agency programs, and fund availability. In order to provide the desired evaluation, qualified Government personnel will conduct reviews and (if necessary) convene panels of experts in the appropriate areas.

For evaluation purposes, a proposal is the document described in “Proposal Information”, Section 4.4.2. Other supporting or background materials submitted with the proposal will be considered for the reviewer's convenience only and not considered as part of the proposal.

Restrictive notices notwithstanding, proposals may be handled for administrative purposes by support contractors. These support contractors are prohibited from competition in DARPA technical research and are bound by appropriate non-disclosure requirements.

Subject to the restrictions set forth in FAR 37.203(d), input on technical aspects of the proposals may be solicited by DARPA from non-Government consultants /experts who are strictly bound by the appropriate non-disclosure requirements.

6. Award Administration Information

6.1. SELECTION NOTICES

As soon as the evaluation of a proposal is complete, the proposers will be notified that: 1) the proposal has been selected for funding pending contract negotiations, or 2) the proposal has not been selected. These official notifications will be sent via email to the Technical POC identified on the proposal coversheet.

6.2. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

6.2.1. Meeting and Travel Requirements

There will be a program kickoff meeting and all key participants are required to attend. Performers should also anticipate regular program-wide PI meetings and periodic site visits at the Program Manager's discretion. Proposers shall include within the content of their proposal details and costs of any travel or meetings they deem to be necessary throughout the course of the effort, to include periodic status reviews by the government.

6.2.2. Human Subjects Research

All research selected for funding involving human subjects, to include use of human biological specimens and human data, must comply with the federal regulations for human subjects protection. Further, research involving human subjects that is conducted or supported by the DoD must comply with 32 CFR 219, Protection of Human Subjects (and DoD Instruction 3216.02, Protection of Human Subjects and Adherence to Ethical Standards in DoD-Supported Research (<http://www.dtic.mil/whs/directives/corres/pdf/321602p.pdf>)).

Institutions awarded funding for research involving human subjects must provide documentation of a current Assurance of Compliance with Federal regulations for human subjects protection, such

as a Department of Health and Human Services, Office of Human Research Protection Federal Wide Assurance (<http://www.hhs.gov/ohrp>). All institutions engaged in human subjects research, to include subawardees, must also hold a valid Assurance. In addition, all personnel involved in human subjects research must provide documentation of completion of human subjects research training.

For all proposed research that will involve human subjects in the first year or phase of the project, the institution must provide evidence of or a plan for review by an Institutional Review Board (IRB) upon final proposal submission to DARPA as part of their proposal, prior to being selected for funding. The IRB conducting the review must be the IRB identified on the institution's Assurance of Compliance with human subjects protection regulations. The protocol, separate from the proposal, must include a detailed description of the research plan, study population, risks and benefits of study participation, recruitment and consent process, data collection, and data analysis. It is recommended that you consult the designated IRB for guidance on writing the protocol. The informed consent document must comply with federal regulations (32 CFR 219.116). A valid Assurance of Compliance with human subjects protection regulations along with evidence of completion of appropriate human subjects research training by all investigators and personnel involved with human subjects research should accompany the protocol for review by the IRB.

In addition to a local IRB approval, a headquarters-level human subjects administrative review and approval is required for all research conducted or supported by the DoD. The Army, Navy, or Air Force office responsible for managing the award can provide guidance and information about their component's headquarters-level review process. Note that confirmation of a current Assurance of Compliance with human subjects protection regulations and appropriate human subjects research training is required before headquarters-level approval can be issued.

The time required to complete the IRB review/approval process varies depending on the complexity of the research and the level of risk involved with the study. The IRB approval process can last between one and three months, followed by a DoD review that could last between three and six months. Ample time should be allotted to complete the approval process. DoD/DARPA funding cannot be used towards human subjects research until ALL approvals are granted.

6.2.3. Animal Use

Award recipients performing research, experimentation, or testing involving the use of animals shall comply with the rules on animal acquisition, transport, care, handling, and use as outlined in: (i) 9 CFR parts 1-4, Department of Agriculture rules that implement the Animal Welfare Act of 1966, as amended, (7 U.S.C. § 2131-2159); (ii) National Institutes of Health Publication No. 86-23, "Guide for the Care and Use of Laboratory Animals" (8th Edition); and (iii) DoD Instruction 3216.01, "Use of Animals in DoD Programs."

For projects anticipating animal use, proposals should briefly describe plans for Institutional Animal Care and Use Committee (IACUC) review and approval. Animal studies in the program will be expected to comply with the Public Health Service (PHS) Policy on Humane Care and Use of Laboratory Animals, available at <http://grants.nih.gov/grants/olaw/olaw.htm>.

All award recipients must receive approval by a DoD-certified veterinarian, in addition to an IACUC approval. No animal studies may be conducted using DoD/DARPA funding until the United States Army Medical Research and Materiel Command (USAMRMC) Animal Care and Use Review Office (ACURO) or other appropriate DoD veterinary office(s) grant approval. As a part of this secondary review process, the award recipient will be required to complete and submit an ACURO Animal Use Appendix, which may be found at https://mrmc-www.army.mil/index.cfm?pageid=Research_Protections.acuro&rn=1.

6.2.4. Export Control

Per DFARS 225.7901-4, all procurement contracts, other transactions and other awards, as deemed appropriate, resultant from this solicitation will include the DFARS Export Control clause (252.225-7048).

6.2.5. Subcontracting

Pursuant to Section 8(d) of the Small Business Act (15 U.S.C. § 637(d)), it is the policy of the Government to enable small business and small disadvantaged business concerns to be considered fairly as subcontractors to contractors performing work or rendering services as prime contractors or subcontractors under Government contracts, and to assure that prime contractors and subcontractors carry out this policy. Each proposer who submits a contract proposal and includes subcontractors is required to submit a subcontracting plan in accordance with FAR 19.702(a) (1) and should do so with their proposal. The plan format is outlined in FAR 19.704.

6.2.6. Electronic and Information Technology

All electronic and information technology acquired through this solicitation must satisfy the accessibility requirements of Section 508 of the Rehabilitation Act (29 U.S.C. § 794d) and FAR 39.2. Each proposer who submits a proposal involving the creation or inclusion of electronic and information technology must ensure that Federal employees with disabilities will have access to and use of information that is comparable to the access and use by Federal employees who are not individuals with disabilities and members of the public with disabilities seeking information or services from DARPA will have access to and use of information and data that is comparable to the access and use of information and data by members of the public who are not individuals with disabilities.

6.2.7. Employment Eligibility Verification

As per FAR 22.1802, recipients of FAR-based procurement contracts must enroll as federal contractors in E-verify and use the system to verify employment eligibility of all employees assigned to the award. All resultant contracts from this solicitation will include FAR 52.222-54, "Employment Eligibility Verification." This clause will not be included in grants, cooperative agreements, or Other Transactions.

6.2.8. System for Award Management (SAM) and Universal Identifier Requirements

Unless the proposer is exempt from this requirement, as per FAR 4.1102 or 2 CFR 25.110 as applicable, all proposers must be registered in the System for Award Management (SAM) and

have a valid Data Universal Numbering System (DUNS) number prior to submitting a proposal. All proposers must maintain an active registration in SAM with current information at all times during which they have an active Federal award or proposal under consideration by DARPA. All proposers must provide the DUNS number in each proposal they submit.

Information on SAM registration is available at www.sam.gov.

6.2.9. Reporting Executive Compensation and First-Tier Subcontract Awards

FAR clause 52.204-10, “Reporting Executive Compensation and First-Tier Subcontract Awards,” will be used in all procurement contracts valued at \$25,000 or more. A similar award term will be used in all grants and cooperative agreements.

6.2.10. Updates of Information Regarding Responsibility Matters

Per FAR 9.104-7(c), FAR clause 52.209-9, Updates of Publicly Available Information Regarding Responsibility Matters, will be included in all contracts valued at \$500,000 or more where the contractor has current active Federal contracts and grants with total value greater than \$10,000,000.

6.2.11. Representations by Corporations Regarding an Unpaid Delinquent Tax Liability or a Felony Conviction under any Federal Law

The following representation will be included in all awards:

(a) In accordance with section 101(a) of the Continuing Appropriations Act, 2016 (Pub. L. 114-53) and any subsequent FY 2016 appropriations act that extends to FY 2016 funds the same restrictions as are contained in sections 744 and 745 of division E, title VII, of the Consolidated and Further Continuing Appropriations Act, 2015 (Pub. L. 113-235), none of the funds made available by this or any other Act may be used to enter into a contract with any corporation that —

(1) Has any unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or have lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability, where the awarding agency is aware of the unpaid tax liability, unless the agency has considered suspension or debarment of the corporation and made a determination that this further action is not necessary to protect the interests of the Government; or

(2) Was convicted of a felony criminal violation under any Federal law within the preceding 24 months, where the awarding agency is aware of the conviction, unless the agency has considered suspension or debarment of the corporation and made a determination that this action is not necessary to protect the interests of the Government.

(b) The Offeror represents that —

(1) It is [] is not [] a corporation that has any unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or have

lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability,

(2) It is ☐ is not ☐ a corporation that was convicted of a felony criminal violation under a Federal law within the preceding 24 months.

6.2.12. Cost Accounting Standards (CAS) Notices and Certification

As per FAR 52.230-2, any procurement contract in excess of the referenced threshold resulting from this solicitation will be subject to the requirements of the Cost Accounting Standards Board (48 CFR 99), except those contracts which are exempt as specified in 48 CFR 9903.201-1. Any proposer submitting a proposal which, if accepted, will result in a CAS compliant contract, must submit representations and a Disclosure Statement as required by 48 CFR 9903.202 detailed in FAR 52.230-2. The disclosure forms may be found at http://www.whitehouse.gov/omb/procurement_casb.

6.2.13. Controlled Unclassified Information (CUI) on Non-DoD Information Systems

Controlled Unclassified Information (CUI) refers to unclassified information that does not meet the standards for National Security Classification but is pertinent to the national interests of the United States or to the important interests of entities outside the Federal Government and under law or policy requires protection from unauthorized disclosure, special handling safeguards, or prescribed limits on exchange or dissemination. All non-DoD entities doing business with DARPA are expected to adhere to the following procedural safeguards, in addition to any other relevant Federal or DoD specific procedures, for submission of any proposals to DARPA and any potential business with DARPA:

- Do not process DARPA CUI on publicly available computers or post DARPA CUI to publicly available webpages or websites that have access limited only by domain or Internet protocol restriction.
- Ensure that all DARPA CUI is protected by a physical or electronic barrier when not under direct individual control of an authorized user and limit the transfer of DARPA CUI to subawardees or teaming partners with a need to know and commitment to this level of protection.
- Ensure that DARPA CUI on mobile computing devices is identified and encrypted and all communications on mobile devices or through wireless connections are protected and encrypted.
- Overwrite media that has been used to process DARPA CUI before external release or disposal.

6.2.14. Safeguarding of Covered Defense Information and Cyber Incident Reporting

Per DFARS 204.7304, DFARS 252.204-7012, “Safeguarding of Covered Defense Information and Cyber Incident Reporting,” applies to this solicitation and all FAR-based awards resulting from this solicitation.

6.2.15. Prohibition on Contracting with Entities that Require Certain Internal Confidentiality Agreements

(a) In accordance with section 101(a) of the Continuing Appropriations Act, 2016 (Pub. L. 114-53) and any subsequent FY 2016 appropriations act that extends to FY 2016 funds the same restrictions as are contained in section 743 of division E, title VII, of the Consolidated and Further Continuing Appropriations Act, 2015 (Pub. L. 113-235), none of the funds appropriated (or otherwise made available) by this or any other Act may be used for a contract with an entity that requires employees or subcontractors of such entity seeking to report fraud, waste, or abuse to sign internal confidentiality agreements or statements prohibiting or otherwise restricting such employees or contractors from lawfully reporting such waste, fraud, or abuse to a designated investigative or law enforcement representative of a Federal department or agency authorized to receive such information.

(b) The prohibition in paragraph (a) of this provision does not contravene requirements applicable to Standard Form 312, Form 4414, or any other form issued by a Federal department or agency governing the nondisclosure of classified information.

(c) *Representation.* By submission of its offer, the Offeror represents that it does not require employees or subcontractors of such entity seeking to report fraud, waste, or abuse to sign or comply with internal confidentiality agreements or statements prohibiting or otherwise restricting such employees or contractors from lawfully reporting such waste, fraud, or abuse to a designated investigative or law enforcement representative of a Federal department or agency authorized to receive such information.

6.3. REPORTING

The number and types of reports will be specified in the award document, but will include as a minimum monthly financial status reports and quarterly technical status reports. The reports shall be prepared and submitted in accordance with the procedures contained in the award document and mutually agreed on before award. Reports and briefing material will also be required as appropriate to document progress in accomplishing program metrics. A Final Report that summarizes the project and tasks will be required at the conclusion of the performance period for the award, notwithstanding the fact that the research may be continued under a follow-on vehicle. Reference 4.4.1.6 for a sample list for complying with this request.

6.4. ELECTRONIC SYSTEMS

6.4.1. Representations and Certifications

In accordance with FAR 4.1201, prospective proposers shall complete electronic annual representations and certifications at <http://orca.bpn.gov>.

6.4.2. Wide Area Work Flow (WAWF)

Unless using another approved electronic invoicing system, performers will be required to submit invoices for payment directly via the Internet/WAWF at <http://wawf.eb.mil>. Registration to WAWF will be required prior to any award under this BAA.

6.4.3.i-EDISON

The award document for each proposal selected for funding will contain a mandatory requirement for patent reports and notifications to be submitted electronically through i-Edison (<http://s-edison.info.nih.gov/iEdison>).

7. Agency Contacts

Administrative, technical or contractual questions should be sent via e-mail to DARPA-BAA-16-24@darpa.mil. All requests must include the name, email address, and phone number of a point of contact.

Points of Contact

The BAA Coordinator for this effort may be reached at:

DARPA-BAA-16-24@darpa.mil.

DARPA/BTO

ATTN: DARPA-BAA-16-24

675 North Randolph Street

Arlington, VA 22203-2114

8. Other Information

8.1. INTELLECTUAL PROPERTY

8.1.1. Procurement Contract Proposers

8.1.1.1 Noncommercial Items (Technical Data and Computer Software)

Proposers responding to this BAA requesting a procurement contract to be issued under the FAR/DFARS, shall identify all noncommercial technical data, and noncommercial computer software that it plans to generate, develop, and/or deliver under any proposed award instrument in which the Government will acquire less than unlimited rights, and to assert specific restrictions on those deliverables. Proposers shall follow the format under DFARS 252.227-7017 for this stated purpose. In the event that proposers do not submit the list, the Government will assume that it automatically has “unlimited rights” to all noncommercial technical data and noncommercial computer software generated, developed, and/or delivered under any award instrument. If mixed funding is anticipated in the development of noncommercial technical data, and noncommercial computer software generated, developed, and/or delivered under any award instrument, then proposers should identify the data and software in question, as subject to Government Purpose Rights (GPR). In accordance with DFARS 252.227-7013 Rights in Technical Data - Noncommercial Items, and DFARS 252.227-7014 Rights in Noncommercial Computer Software and Noncommercial Computer Software Documentation, the Government will automatically assume that any such GPR restriction is limited to a period of five (5) years in accordance with the applicable DFARS clauses, at which time the Government will acquire “unlimited rights” unless the parties agree otherwise. Proposers are advised that the Government will use the list during the source selection evaluation process to evaluate the impact of any identified restrictions, and may request additional information from the proposer, as may be necessary, to evaluate the proposer’s assertions. If no restrictions are intended, then the proposer should state “NONE.” It is noted an

assertion of “NONE” indicates that the Government has “unlimited rights” to all noncommercial technical data and noncommercial computer software delivered under the award instrument, in accordance with the DFARS provisions cited above. Failure to provide full information may result in a determination that the proposal is not compliant with the BAA – resulting in nonselectability of the proposal.

A sample list for complying with this request is as follows:

NONCOMMERCIAL				
Technical Data Computer Software To be Furnished With Restrictions	Summary of Intended Use in the Conduct of the Research	Basis for Assertion	Asserted Rights Category	Name of Person Asserting Restrictions
(LIST)	(NARRATIVE)	(LIST)	(LIST)	(LIST)

8.1.1.2 Commercial Items (Technical Data and Computer Software)

Proposers responding to this BAA requesting a procurement contract to be issued under the FAR/DFARS, shall identify all commercial technical data, and commercial computer software that may be embedded in any noncommercial deliverables contemplated under the research effort, along with any applicable restrictions on the Government’s use of such commercial technical data and/or commercial computer software. In the event that proposers do not submit the list, the Government will assume that there are no restrictions on the Government’s use of such commercial items. The Government may use the list during the source selection evaluation process to evaluate the impact of any identified restrictions, and may request additional information from the proposer, as may be necessary, to evaluate the proposer’s assertions. If no restrictions are intended, then the proposer should state “NONE.” Failure to provide full information may result in a determination that the proposal is not compliant with the BAA – resulting in nonselectability of the proposal.

A sample list for complying with this request is as follows:

COMMERCIAL				
Technical Data Computer Software To be Furnished With Restrictions	Summary of Intended Use in the Conduct of the Research	Basis for Assertion	Asserted Rights Category	Name of Person Asserting Restrictions
(LIST)	(NARRATIVE)	(LIST)	(LIST)	(LIST)

8.1.2. Non-Procurement Contract Proposers - Noncommercial and Commercial Items (Technical Data and Computer Software)

Proposers responding to this BAA requesting an Other Transaction for Prototype shall follow the applicable rules and regulations governing that instrument, but in all cases should appropriately identify any potential restrictions on the Government’s use of any Intellectual Property contemplated under that award instrument. This includes both Noncommercial Items and Commercial Items. Although not required, proposers may use a format similar to that described in Paragraphs 1.a and 1.b above. The Government may use the list during the source selection

evaluation process to evaluate the impact of any identified restrictions, and may request additional information from the proposer, as may be necessary, to evaluate the proposer's assertions. If no restrictions are intended, then the proposer should state "NONE." Failure to provide full information may result in a determination that the proposal is not compliant with the BAA – resulting in nonselectability of the proposal.

8.1.3. All Proposers – Patents

Include documentation proving your ownership of or possession of appropriate licensing rights to all patented inventions (or inventions for which a patent application has been filed) that will be utilized under your proposal for the DARPA program. If a patent application has been filed for an invention that your proposal utilizes, but the application has not yet been made publicly available and contains proprietary information, you may provide only the patent number, inventor name(s), assignee names (if any), filing date, filing date of any related provisional application, and a summary of the patent title, together with either: 1) a representation that you own the invention, or 2) proof of possession of appropriate licensing rights in the invention.

8.1.4. All Proposers-Intellectual Property Representations

Provide a good faith representation that you either own or possess appropriate licensing rights to all other intellectual property that will be utilized under your proposal for the DARPA program. Additionally, proposers shall provide a short summary for each item asserted with less than unlimited rights that describes the nature of the restriction and the intended use of the intellectual property in the conduct of the proposed research.