Department of Defense
Fiscal Year (FY) 2020 Budget Estimates

March 2019

Defense Advanced Research Projects Agency

Defense-Wide Justification Book Volume 1 of 5

Research, Development, Test & Evaluation, Defense-Wide

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Department of Defense
FY 2020 President's Budget
Exhibit R-1 FY 2020 President's Budget
Total Obligational Authority
(Dollars in Thousands)

25 Feb 2019

Appropriation	FY 2018 (Base + OCO)	FY 2019 Base Enacted	FY 2019 OCO Enacted	FY 2019 Total Enacted
Research, Development, Test & Eval, DW	3,088,620	3,427,049		3,427,049
Total Research, Development, Test & Evaluation	3,088,620	3,427,049		3,427,049

R-120PB: FY 2020 President's Budget (Published Version), as of February 25, 2019 at 07:44:36

Department of Defense
FY 2020 President's Budget
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(Dollars in Thousands)

25 Feb 2019

Appropriation	FY 2020 Base	FY 2020 OCO for Base Requirements	FY 2020 OCO for Direct War and Enduring Costs	FY 2020 Total OCO	FY 2020 Total (Base + OCO)
Research, Development, Test & Eval, DW	3,556,221				3,556,221
Total Research, Development, Test & Evaluation	3,556,221				3,556,221

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Department of Defense
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25 Feb 2019

Summary Recap of Budget Activities	FY 2018 (Base + OCO)	FY 2019 Base Enacted	FY 2019 OCO Enacted	FY 2019 Total Enacted
Basic Research	445,577	469,255		469,255
Applied Research	1,251,635	1,407,118		1,407,118
Advanced Technology Development	1,212,318	1,471,387		1,471,387
Management Support	179,090	79,289		79,289
Total Research, Development, Test & Evaluation	3,088,620	3,427,049		3,427,049
Summary Recap of FYDP Programs				
Research and Development	3,088,620	3,427,049		3,427,049
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Department of Defense
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25 Feb 2019

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Basic Research	486,406				486,406
Applied Research	1,468,685				1,468,685
Advanced Technology Development	1,519,424				1,519,424
Management Support	81,706				81,706
Total Research, Development, Test & Evaluation	3,556,221				3,556,221
Summary Recap of FYDP Programs					
Research and Development	3,556,221				3,556,221
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Defense-Wide
FY 2020 President's Budget
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25 Feb 2019

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

Line No	Program Element Number	Item	Act	FY 2018 (Base + OCO)	FY 2019 Base Enacted	FY 2019 OCO Enacted	FY 2019 Total Enacted	Sec
2	0601101E	Defense Research Sciences	01	403,448	422,680		422,680	U
4	0601117E	Basic Operational Medical Research Science	01	42,129	46,575		46,575	U
	Basic Research			445,577	469,255		469,255	
9	0602115E	Biomedical Technology	02	88,962	101,300		101,300	U
13	0602303E	Information & Communications Technology	02	379,578	404,967		404,967	U
14	0602383E	Biological Warfare Defense	02	15,078	33,640		33,640	U
17	0602702E	Tactical Technology	02	292,957	309,466		309,466	U
18	0602715E	Materials and Biological Technology	02	191,880	208,898		208,898	U
19	0602716E	Electronics Technology	02	283,180	348,847		348,847	U
	Applied Research			1,251,635	1,407,118		1,407,118	
33	0603286E	Advanced Aerospace Systems	03	176,200	302,463		302,463	U
34	0603287E	Space Programs and Technology	03	226,988	254,671		254,671	U
54	0603739E	Advanced Electronics Technologies	03	73,673	111,099		111,099	U
55	0603760E	Command, Control and Communications Systems	03	103,577	185,984		185,984	U
56	0603766E	Network-Centric Warfare Technology	03	429,691	434,069		434,069	U
57	0603767E	Sensor Technology	03	202,189	183,101		183,101	U
	Advanced Technology Development			1,212,318	1,471,387		1,471,387	
147	0605001E	Mission Support	06	64,269	65,646		65,646	U
162	0605502E	Small Business Innovative Research	06	100,804				U

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2	0601101E	Defense Research Sciences	01	432,284				432,284	U
4	0601117E	Basic Operational Medical Research Science	01	54,122				54,122	U
	Basic Research			486,406				486,406	
9	0602115E	Biomedical Technology	02	97,771				97,771	U
13	0602303E	Information & Communications Technology	02	442,556				442,556	U
14	0602383E	Biological Warfare Defense	02	34,588				34,588	U
17	0602702E	Tactical Technology	02	337,602				337,602	U
18	0602715E	Materials and Biological Technology	02	223,976				223,976	U
19	0602716E	Electronics Technology	02	332,192				332,192	U
	Applied Research			1,468,685				1,468,685	
33	0603286E	Advanced Aerospace Systems	03	279,741				279,741	U
34	0603287E	Space Programs and Technology	03	202,606				202,606	U
54	0603739E	Advanced Electronics Technologies	03	128,616				128,616	U
55	0603760E	Command, Control and Communications Systems	03	232,134				232,134	U
56	0603766E	Network-Centric Warfare Technology	03	512,424				512,424	U
57	0603767E	Sensor Technology	03	163,903				163,903	U
	Advanced Technology Development			1,519,424				1,519,424	
147	0605001E	Mission Support	06	68,498				68,498	U
162	0605502E	Small Business Innovative Research	06						U

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172	0605898E	Management HQ - R&D	06	14,017	13,643		13,643	U
		Management Support		179,090	79,289		79,289	
Total Research, Development, Test & Eval, DW				3,088,620	3,427,049		3,427,049	

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172	0605898E	Management HQ - R&D	06	13,208				13,208	U
		Management Support		81,706				81,706	
Total Research, Development, Test & Eval, DW				3,556,221				3,556,221	

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Total Defense Advanced Research Projects Agency				3,556,221				3,556,221	

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

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4	01	0601117E	BASIC OPERATIONAL MEDICAL SCIENCE	Volume 1 - 47

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 - 53
13	02	0602303E	INFORMATION & COMMUNICATIONS TECHNOLOGY	Volume 1 - 61
14	02	0602383E	BIOLOGICAL WARFARE DEFENSE	Volume 1 - 91
17	02	0602702E	TACTICAL TECHNOLOGY	Volume 1 - 95
18	02	0602715E	MATERIALS AND BIOLOGICAL TECHNOLOGY	Volume 1 - 121
19	02	0602716E	ELECTRONICS TECHNOLOGY	Volume 1 - 137

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

Line #	Budget Activity	Program Element Number	Program Element Title	Page
33	03	0603286E	ADVANCED AEROSPACE SYSTEMS	Volume 1 - 161
34	03	0603287E	SPACE PROGRAMS AND TECHNOLOGY	Volume 1 - 171
54	03	0603739E	ADVANCED ELECTRONICS TECHNOLOGIES	Volume 1 - 181
55	03	0603760E	COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS	Volume 1 - 193
56	03	0603766E	NETWORK-CENTRIC WARFARE TECHNOLOGY	Volume 1 - 205
57	03	0603767E	SENSOR TECHNOLOGY	Volume 1 - 225

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

Line #	Budget Activity	Program Element Number	Program Element Title	Page
147	06	0605001E	MISSION SUPPORT	Volume 1 - 241
162	06	0605502E	SMALL BUSINESS INNOVATION RESEARCH	Volume 1 - 243
172	06	0605898E	MANAGEMENT HQ - R&D	Volume 1 - 245

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Program Element Title	Program Element Number	Line #	BA	Page
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ADVANCED ELECTRONICS TECHNOLOGIES	0603739E	54	03	Volume 1 - 181
BASIC OPERATIONAL MEDICAL SCIENCE	0601117E	4	01	Volume 1 - 47
BIOLOGICAL WARFARE DEFENSE	0602383E	14	02	Volume 1 - 91
BIOMEDICAL TECHNOLOGY	0602115E	9	02	Volume 1 - 53
COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS	0603760E	55	03	Volume 1 - 193
DEFENSE RESEARCH SCIENCES	0601101E	2	01	Volume 1 - 1
ELECTRONICS TECHNOLOGY	0602716E	19	02	Volume 1 - 137
INFORMATION & COMMUNICATIONS TECHNOLOGY	0602303E	13	02	Volume 1 - 61
MANAGEMENT HQ - R&D	0605898E	172	06	Volume 1 - 245
MATERIALS AND BIOLOGICAL TECHNOLOGY	0602715E	18	02	Volume 1 - 121
MISSION SUPPORT	0605001E	147	06	Volume 1 - 241
NETWORK-CENTRIC WARFARE TECHNOLOGY	0603766E	56	03	Volume 1 - 205
SENSOR TECHNOLOGY	0603767E	57	03	Volume 1 - 225
SMALL BUSINESS INNOVATION RESEARCH	0605502E	162	06	Volume 1 - 243
SPACE PROGRAMS AND TECHNOLOGY	0603287E	34	03	Volume 1 - 171
TACTICAL TECHNOLOGY	0602702E	17	02	Volume 1 - 95

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Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 1: *Basic Research*	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	403.448	422.680	432.284	-	432.284	431.356	414.402	392.564	382.423	-	-
CCS-02: *MATH AND COMPUTER SCIENCES*	-	174.658	188.629	220.824	-	220.824	236.716	226.076	213.572	219.536	-	-
CYS-01: *CYBER SCIENCES*	-	44.094	12.801	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-
ES-01: *ELECTRONIC SCIENCES*	-	69.001	41.032	43.333	-	43.333	35.083	36.883	34.883	34.883	-	-
ES-02: *BEYOND SCALING SCIENCES*	-	0.000	51.100	47.000	-	47.000	43.800	38.700	53.290	53.290	-	-
MS-01: *MATERIALS SCIENCES*	-	65.675	77.919	63.412	-	63.412	65.436	62.255	60.138	50.138	-	-
TRS-01: *TRANSFORMATIVE SCIENCES*	-	50.020	51.199	57.715	-	57.715	50.321	50.488	30.681	24.576	-	-

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, and materials sciences.

The Math and Computer Sciences project supports scientific study and experimentation on new mathematical and computational algorithms, models, and mechanisms in support of long-term national security requirements. Modern analytic and information technologies enable important new military capabilities and drive the productivity gains essential to U.S. economic competitiveness. Conversely, new classes of threats, in particular threats that operate in or through the cyber domain, put military systems, critical infrastructure, and the civilian economy at risk. This project aims to magnify these opportunities and mitigate these threats by leveraging emerging mathematical and computational capabilities including computational social science, artificial intelligence, machine learning and reasoning, data science, complex systems modeling and simulation, and theory of computation. The basic research conducted under the Math and Computer Sciences project will produce breakthroughs that enable new capabilities for national security and homeland defense.

The Cyber Sciences project supports long-term national security requirements through scientific research and experimentation in cyber security. Information technologies enable important new military capabilities and drive the productivity gains essential to U.S. economic competitiveness. Meanwhile, cyber threats grow in sophistication and number, and put sensitive data, classified computer programs, mission-critical information systems, and future economic gains at risk. The basic research conducted under the Cyber Sciences project will produce breakthroughs necessary to enhance the resilience of DoD information systems to current and emerging cyber threats.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 1: *Basic Research*	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*

The Electronic Sciences project is for basic exploration of electronic and optoelectronic devices, circuits, and processing concepts to meet the military's need for near real-time information gathering, transmission, and processing. In seeking to continue the phenomenal progress in microelectronics innovation that has characterized the last few decades, the project should provide DoD with new, improved, or potentially revolutionary device options for accomplishing these critical functions. The resulting technologies should help maintain knowledge of the enemy, communicate decisions based on that knowledge, and substantially improve the cost and performance of military systems. Research areas include analog, mixed signal, and photonic circuitry for communications and other applications; alternative computer architectures; and magnetic components to reduce the size of Electromagnetic (EM) and sensing systems. Other research could support field-portable electronics with reduced power requirements, ultra-high density information storage "on-a-chip", and new approaches to nanometer-scale structures, molecules, and devices.

The Beyond Scaling Sciences project will support investigations into materials, devices, and architectures to provide continued improvements in electronics performance with or without the benefit of Moore's Law (silicon scaling). Within the next ten years, traditional scaling will start to encounter the fundamental physical limits of silicon, requiring fresh approaches to new electronic systems. Over the short term, DoD will therefore need to unleash circuit specialization in order to maximize the benefit of traditional silicon. Over the longer term, DoD and the nation will need to engage the computer, material, and mechanical sciences to explore electronics improvements through new non-volatile memory devices that combine computation, memory, and new automated design tools using machine learning. Other memory devices could also leverage an emerging understanding of the physics of magnetic states, electron spin properties, topological insulators, or phase-changing materials. Beyond Scaling programs will address fundamental exploration into each of these areas.

The Materials Sciences project provides the fundamental research that underpins the design, development, assembly, and optimization of advanced materials, devices, and systems for DoD applications in areas such as robust diagnostics and therapeutics, novel energetic materials, and complex hybrid systems.

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 or threaten National Security. Specific research in this project will investigate technologies to enable detection of novel threat agents (e.g., bacterial pathogens) and maintain warfighter health, as well as create innovative materials of interest to the military (e.g., self-healing materials).

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 1: *Basic Research*	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*

B. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	432.347	422.130	413.970	-	413.970
Current President's Budget	403.448	422.680	432.284	-	432.284
Total Adjustments	-28.899	0.550	18.314	-	18.314
• Congressional General Reductions	-14.510	-14.450			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	15.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	-2.638	0.000			
• SBIR/STTR Transfer	-11.751	0.000			
• TotalOtherAdjustments	-	-	18.314	-	18.314

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2018	FY 2019
Project: CCS-02: *MATH AND COMPUTER SCIENCES*		
Congressional Add: *DARPA Foundational and Applied Artificial Intelligence*	-	15.000
Congressional Add Subtotals for Project: CCS-02	-	15.000
Congressional Add Totals for all Projects	-	15.000

Change Summary Explanation

FY 2018: Decrease reflects Congressional reduction, SBIR/STTR transfer and reprogrammings.

FY 2019: Increase reflects Congressional adjustments.

FY 2020: Increase reflects expansion of Artificial Intelligence initiatives, offset by smaller program decreases.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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*	

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
CCS-02: *MATH AND COMPUTER SCIENCES*	-	174.658	188.629	220.824	-	220.824	236.716	226.076	213.572	219.536	-	-

A. Mission Description and Budget Item Justification

The Math and Computer Sciences project supports scientific study and experimentation on new mathematical and computational algorithms, models, and mechanisms in support of long-term national security requirements. Modern analytic and information technologies enable important new military capabilities and drive the productivity gains essential to U.S. economic competitiveness. Conversely, new classes of threats, in particular threats that operate in or through the cyber domain, put military systems, critical infrastructure, and the civilian economy at risk. This project aims to magnify these opportunities and mitigate these threats by leveraging emerging mathematical and computational capabilities including computational social science, artificial intelligence, machine learning and reasoning, data science, complex systems modeling and simulation, and theory of computation. The basic research conducted under the Math and Computer Sciences project will produce breakthroughs that enable new capabilities for national and homeland security.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Human Social Systems	18.767	26.608	27.000

Description: The social sciences provide essential theories and models that can enable deeper understanding of human social systems and behaviors relevant to national security such as humanitarian aid, disaster relief, and stability support missions, as well as tactical, operational, strategic, and policy-level decision-making across the DoD. However, current limitations to the speed, scalability and reproducibility of empirical social science research continue to hamper its practical use by the DoD. Additionally, current social behavioral models often fail to accurately interpret social behaviors because they do not sufficiently capture diversity of context. The Human Social Systems thrust will address these limitations by focusing on the following technical challenges: (1) developing and validating new methods, models and tools to perform rigorous, reproducible experimental research at scales necessary to understand emergent properties of human social systems; (2) identifying methods to better characterize and quantify properties, dynamics, and behaviors of different social systems to enable better and more confident forecasting of changes in social systems, particularly when under stress; and (3) developing an understanding of the complex effect of context and incorporating these effects into social science models. This research thrust will provide DoD with new, reliable strategies to better understand and respond to social system issues at city scale and will significantly improve DoD ability to assess intent, deception, and other social behaviors.

FY 2019 Plans:

- Integrate new capabilities for experimentally testing and validating multiple models of human social systems and behavior.
- Develop scoring methods to quantify the predictive accuracy of different models across different social experimental designs.
- Test the efficiency and value of enhanced reproducibility for accelerating rigorous understanding of human social systems and behaviors.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Develop and deploy increasingly complex social simulations with known causal ground truth as test bed challenges for social science research communities. - Quantify the diagnostic and predictive accuracy, robustness, and efficiency of social science representation and modeling tools by testing them against simulations. - Determine the capabilities and limitations of representation and modeling tools for understanding and predicting cause and effect in complex social systems. - Measure bias in systems trained on distinct training sets and apply understanding of group biases to specific use cases. - Formalize definitions of reproducibility and replicability for social and behavioral science research. - Develop new capabilities for rapidly assigning quantitative confidence scores to social and behavioral science research. - Explore analogous systems to improve societal systems models used by military decision-makers engaged in conflict resolution. ***FY 2020 Plans:*** - Develop and deploy highly complex social simulations with known causal ground truth as test bed challenges for social science research communities. - Quantify the diagnostic and predictive accuracy, robustness, and efficiency of social science representation and modeling tools by testing them against simulations. - Determine the capabilities and limitations of representation and modeling tools for understanding and predicting cause and effect in highly complex social systems. - Demonstrate efficiency and value of rapid, scalable replication capabilities for accelerating rigorous understanding of human social systems and behaviors. - Implement and test algorithms for automatically assigning quantitative confidence scores to social and behavioral science research. - Develop capabilities for adjusting algorithms based on user-specific needs and interests. - Initiate development of a taxonomy of social contexts and human-centric context-aware models that accounts for the specifics of a given situation, including cultural differences. - Demonstrate feasibility for expanding consideration of context in social science models to enhance interpretation of social behavior including intent and deception. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects minor program repricing.			
Title: Synergistic Discovery and Design (SD2)	19.000	20.000	21.000
Description: The Synergistic Discovery and Design (SD2) program is developing data-driven methods to accelerate scientific discovery and robust design in domains that lack complete models. Engineers regularly use high-fidelity simulations to create robust designs in complex domains such as aeronautics and integrated circuits. In contrast, robust design remains elusive in			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
domains such as synthetic biology, neuro-computation, and synthetic chemistry due to the lack of high-fidelity models. The SD2 program will collect raw experimental data into a data and analysis hub, develop computational techniques that extract scientific knowledge directly from experimental data, and create data sharing tools and metrics that facilitate collaborative design. SD2 application domains include synthetic biology, solar cell chemistry, and protein design, which will impact future DoD capabilities in areas such as chemical and biological defense, and warfighter readiness. ***FY 2019 Plans:*** - Extend scientific discovery algorithms to understand why experiments fail, and to enhance reproducibility of experiments. - Establish tools for automated design of novel solar materials, improve accuracy of protein and riboswitch design tools, and extend design tool capabilities to enable biological circuit design. - Enhance experimental planning tools to facilitate design of experiments that maximize information gained on a per-experiment basis. - Extend baseline protocol capture software to enable assembly of high-quality, integrated, experimental data, and evaluate generalizability of approach. ***FY 2020 Plans:*** - Apply discovery algorithms to novel systems that have not been characterized by human experts. - Integrate discovery algorithms with design protocols to automate the experimental process. - Improve experimental planning tools to reduce the experimental costs required to obtain a functional design. - Scale software and infrastructure to process petabytes of experimental data, and evaluate tools by testing their ability to adapt protein, riboswitch, and cellular circuit designs into biosensors. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects minor program repricing.			
Title: World Modelers ***Description:*** The World Modelers program is creating explanatory models for natural and human-mediated systems at regional and global scales. The world is highly interdependent, and disruption of natural resources, supply chains, and production systems can have severe consequences. The World Modelers capability is focused on regional and global systems with the goal of generating timely indications and warnings of impending catastrophe. Water and food security are application domains of particular interest, as persistent drought may cause crops to fail, leading to migration and regional conflicts. The World Modelers program is developing techniques for automating the creation, maintenance, and validation of large-scale integrated models using publicly available news and analyst reports as a structuring mechanism, and government and commercial data as quantitative inputs. Advances in machine reading and learning, semantic technologies, big data analysis, geo-spatial and economic modeling, and environmental simulation bring this strategic capability within reach.	15.633	16.000	17.500

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
FY 2019 Plans: - Develop advanced capabilities for perturbation modeling and apply technology to additional use cases, in particular, migration and other factors that can provoke conflict among local populations. - Integrate technologies into an initial end-to-end workflow: build qualitative models, parameterize quantitative models, automate machine processing from scenarios to actions, and generate uncertainty reporting. - Evaluate integrated workflow on use cases, such as food security and migration. - Work with DoD and Intelligence Community (IC) stakeholders to demonstrate and test the technologies on high-priority use cases, and coordinate with Department of Homeland Security (DHS) to consider the potential for applying the technology to domestic use cases such as disaster relief. ***FY 2020 Plans:*** - Develop models for acute, high-impact phenomena such as natural disasters and disruption of civilian infrastructure on regional scales. - Extend the integrated workflow to operate on compressed temporal scales and apply to use cases involving acute, high-impact phenomena. - Evaluate and optimize the extended workflow on food security, migration, and acute, high-impact use cases. - Perform demonstrations on realistic scenarios in collaboration with DoD, IC, DHS, and other stakeholders and potential transition sponsors. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects minor program repricing.			
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 fifteen topic areas spanning from Machine Learning and Many Body Physics, to Wideband Transmitter-Antenna Interfaces and Multi-Scale Models of Infectious Disease Dynamics. 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 2019 Plans:***	17.000	17.000	17.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Award new FY 2019 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 2018 research on new concepts for microsystem, biological, strategic, and tactical technologies; information innovation; and defense sciences by exercising second year funding and by providing continued mentorship by program managers. - Award Director's Fellowships for top FY 2017 participants to refine technology further and align to DoD needs. ***FY 2020 Plans:*** - Award new FY 2020 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 2019 research on new concepts for microsystem, biological, strategic, and tactical technologies; information innovation; and defense sciences by exercising second year funding and by providing continued mentorship by program managers. - Award Director's Fellowships for top FY 2018 participants to refine technology further and align to DoD needs.			
Title: Advanced Tools for Modeling and Simulation	13.466	14.200	15.400
Description: The Advanced Tools for Modeling and Simulation thrust will develop foundational mathematical, computational, and multi-physics theories, approaches and tools to better represent, quantify and model complex DoD systems from multimodal data analysis through part/system design and fabrication. One focus area of this thrust is developing a unified mathematical framework to enable better visualization and analysis of massive, complex data sets. Rigorous mathematical theories are also being developed to address uncertainty in the modeling and design of complex multi-scale physical and engineering systems, incorporating capabilities to handle noisy data and model uncertainty that are well beyond the scope of current capabilities. Other work in this thrust focuses on developing the mathematical and computational tools required to generate and better manage the enormous complexity of design, ultimately allowing designers to more easily discover non-intuitive (yet realizable) designs that fully leverage new materials and advanced manufacturing approaches now available. Outcomes from this thrust will improve the speed and accuracy of modeling and simulation, as well as enable management of complexity across DoD devices, parts and systems. Another focus area of this thrust is multi-physics models for predicting behavior and non-intuitive failure pathways for complex, dynamic physical systems. ***FY 2019 Plans:*** - Incorporate variability in shaping and material properties under multiple types of physics in analysis and synthesis of real world designs. - Investigate multi-physics analysis and synthesis capabilities for multiple different design representations. - Demonstrate efficacy of alternative design approaches on DoD relevant design challenge problems. - Demonstrate rapidly adaptable conceptual design on a DoD relevant problem.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Explore use of novel conceptual design mathematics and computer science building blocks for evolutionary design. - Transition novel conceptual design software prototypes to government partners for exploration. - Develop general approach to automate creation of adaptable virtual models from heterogeneous data. - Initiate development of approaches that can identify and track the evolution of patterns within a dynamical system in order to simplify solutions by dimensional reduction. - Quantify performance of physics-based architectures, algorithms, and approaches in comparison to alternative state-of-the art approaches. ***FY 2020 Plans:*** - Transition developed technologies and software prototypes to government partners for further exploration. - Incorporate uncertainty into multi-physics analysis and synthesis capabilities. - Develop techniques based on data analysis and machine learning tools to guide design exploration and find promising designs. - Develop multi-physics solvers to cross-compile between different physics (chemical, fluid dynamics, etc.). - Demonstrate the potential for exploiting advances in stochastic methods to quantify risk, including the identification of rare events and non-intuitive behaviors and failure pathways. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects expanded research in the development of multi-physics models to predict behavior and non-intuitive failure pathways for complex, dynamic physical systems.			
Title: Communicating With Computers (CWC)	15.000	16.000	10.565
Description: The Communicating With Computers (CWC) program is advancing human-computer interaction by enabling computers to comprehend language, gesture, facial expression and other communicative modalities in context. Since the very beginning of the field, artificial intelligence has sought to create machines that can use language, interact naturally with humans, and form abstractions and concepts. Human language is inherently ambiguous, so humans depend strongly on perception of the physical world and shared context to communicate efficiently. CWC will 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. CWC will also extend the communication techniques developed for physical contexts to nonphysical contexts and virtual constructs. These CWC advances in foundational areas of artificial intelligence will contribute to future military capabilities in robotics and command and control. ***FY 2019 Plans:***			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Enhance multi-modal communication techniques to increase robustness and minimize breakdowns in context-aware communication. - Develop capability for communication that produces content that is interesting and engaging. - Integrate performer teams across multiple use cases and demonstrate the capability for one machine or system to seamlessly address multiple use cases. ***FY 2020 Plans:*** - Evaluate final technologies against hallmarks of communication that are applicable across multiple program use cases. - Demonstrate a collaborative agent for human-machine communication, extending and leveraging human capacity to plan and execute diverse tasks across multiple domains. - Evaluate technologies across multiple task domains (robotics, knowledge management, content creation) and use cases (blocks, biocuration, and collaborative composition), and transition successful techniques to military and industrial applications. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects ramping down of development of human-computer interaction technologies and a shift in focus to demonstrations and evaluation of human-machine communication capabilities.			
Title: Complex Hybrid Systems	10.500	8.500	6.500
Description: The Complex Hybrid Systems program thrust is focused on exploring fundamental science, mathematics, and computational approaches to collectives, complex hybrid (e.g., human-machine) systems and systems-of-systems across a variety of DoD-relevant domains. Efforts include development of foundational, quantitative theories and algorithms for the analysis and design of complex systems, as well as novel testing capabilities for assessing the value of these theories using experimental verification across multiple problem domains. Results from this thrust will better enable the systematic design of complex hybrid systems that can achieve unprecedented resilience and adaptability in unexpected environments. ***FY 2019 Plans:*** - Advance development of design tools for the optimization of collaborative problem solving performance in human-machine systems and systems-of-systems. - Advance development of a small infantry unit experimental environment that can test the impact of variation of human-machine system configuration. - Demonstrate the use of knowledge representation, including a multi-level grammar approach, and design tools to produce quantitative explanations of the structure and problem solving strategy of high performing teams with machine elements. - Identify massive simulation capabilities with potential to enable new modeling of local/global contexts including retrospectives.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Initiate efforts to enable Artificial Intelligence (AI) systems that handle unknown unknowns gracefully without having to solve the AI Complete problem. ***FY 2020 Plans:*** - Demonstrate simultaneous design and integrated exploration of team structure, capabilities, and problem solving strategies in a dynamic experimental environment. - Conduct multiple demonstrations of the use of knowledge representation and design tools to predict team structure and problem solving strategy of high performing teams with machine elements. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects consolidated research efforts focused on the development of multi-physics models to predict behavior and non-intuitive failure pathways for complex, dynamic physical systems.			
Title: Building Resource Adaptive Software from Specifications (BRASS)	17.450	13.170	4.000
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 paradigm 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 resource-based specifications, and implement compiler and runtime transformations that can efficiently adapt to resource changes. ***FY 2019 Plans:*** - Develop scalable whole-system, resource-aware analysis tools to infer deep resource-based specifications. - Develop optimizing and embeddable compilers to synthesize resource-efficient program variants. - Extend synthesis tools to automatically discover and monitor resource changes for large-scale software systems such as robotics operating systems. - Construct integrated toolchains that automatically adapt software to changing resource conditions, and demonstrate and evaluate the effectiveness of the integrated adaptation technologies on laboratory systems. ***FY 2020 Plans:***			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Based on the effectiveness of the adaptation technologies on laboratory and operational use cases, perform final improvements to adaptation modules and systems and transition technologies to open source repositories, industry, and DoD. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease is the result of development work concluding, and the focus shifting to finalizing and transitioning the runtime verification and adaptive program transformation techniques.			
Title: Guaranteeing AI Robustness against Deception (GARD) ***Description:*** The Guaranteeing AI Robustness against Deception (GARD) program, expanding on technical challenges encountered in the Lifelong Learning Machines program, will develop techniques to make artificial intelligence (AI) and machine learning (ML) algorithms and systems more robust in the presence of deceptive data and adversarial attack. Concurrent with the recent explosion of interest in ML, deception attacks that manipulate a ML system into an erroneous response have also emerged. While such deception attacks against ML have become sophisticated and varied, the development of defensive capabilities for ML systems has not been maintained. The GARD program will address the growing need for defensive ML capabilities by developing techniques to establish robustness properties of ML systems, and to defend against possible attacks. The techniques developed under RAIAD will be essential if the DoD is to rely on ML systems in contested environments. ***FY 2019 Plans:*** - Identify causes of vulnerability and develop metrics for the robustness of ML algorithms. ***FY 2020 Plans:*** - Develop methodologies to increase the robustness of ML systems to deceptive data and adversarial attacks. - Develop and implement defensive techniques for ML systems. - Implement a testbed for ML risk evaluation through challenge problems, attack simulation, and open competitions. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects ramping up of development of robust ML techniques and initial implementation of an ML risk evaluation testbed.	-	6.100	17.244
Title: Machine Common Sense (MCS) ***Description:*** The Machine Common Sense (MCS) program will explore approaches to enable commonsense reasoning by machines. Recent advances in machine learning have resulted in exciting new artificial intelligence (AI) capabilities in areas such as image recognition, natural language processing, and two-person strategy games such as Chess and Go. In all of these application domains, the machine reasoning is narrow and highly specialized, and the machine must be carefully trained or programmed for every situation. General machine commonsense reasoning, on par with human cognition, remains elusive. MCS will develop computational models that mimic core systems of human cognitive development that are grounded in perceptual,	-	13.525	16.815

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
motor, and memory modalities; develop simulated interaction and learning environments to support machine manipulation of grounded concept models; and develop a commonsense knowledge repository to support AI system development. AI systems that are capable of more human-like reasoning will be able to behave reasonably in unforeseen situations. ***FY 2019 Plans:*** - Develop initial approaches for modeling the core systems of human cognition for intuitive physics, spatial locations, and intentional agents. - Develop machine learning methods and techniques to extract commonsense knowledge from the web. ***FY 2020 Plans:*** - Develop a suite of models of core cognition using a variety of AI approaches, to include deep learning, probabilistic simulation, and symbolic reasoning. - Develop techniques for evaluating AI models of core cognition against known human cognitive development milestones, using the simulation environments to assess the realism of core models. - Initiate development of simulation environments for AI systems to interact, learn, and test their models of core cognition. - Begin testing the extracted common knowledge repositories against a suite of commonsense challenge problems. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects ramping up of research and development and initial testing of machine common sense technologies.			
Title: Learning with Less Labels (LwLL)	-	6.250	14.500
Description: The Learning with Less Labels (LwLL) program, addressing a key issue encountered by the Data-Driven Discovery of Models program (budgeted in PE 0602702E, Project TT-13), will develop technology to greatly reduce the amount of labeled data required to train machine learning (ML) systems. In supervised ML, the system learns by example to recognize things, such as objects in images or speech. Humans provide these examples to ML systems during their training in the form of labeled data. With enough labeled data on which to train ML systems, it is generally possible to build useful models, but training accurate models currently requires large amounts of labeled data that can be costly to obtain. LwLL will address this problem by creating ML algorithms that learn and adapt more efficiently than current ML approaches, and by formally deriving the limits of machine learning and adaptation. LwLL-based ML systems will be easier to train and use in variable, unpredictable, real-world environments. ***FY 2019 Plans:***			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Introduce ML algorithms that require less labeled data to achieve a specified performance level including hybrid supervised-unsupervised ML approaches that can be trained using both labeled and unlabeled data. ***FY 2020 Plans:*** - Formulate ML algorithms that are robust to distributional mismatch between the data on which the system is trained and the data on which the system operates post training. - Develop estimates for the rate at which an ML system will converge with increased training in terms of the hyperparameters of the system. - Construct challenge problems and associated labeled and unlabeled data sets, and demonstrate increased learning rates and distributional robustness of the new ML algorithms. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects ramping up of research and development of ML techniques that require less labeled data for effective training.			
Title: Safe Documents (SafeDocs) ***Description:*** The Safe Documents (SafeDocs) program, expanding on foundational issues encountered by the Building Resource Adaptive Software from Specifications program, will develop software technologies that reduce syntactic complexity of data formats and improve the capability to reject invalid and maliciously crafted data in electronic documents and streaming data. The high complexity of electronic documents and streaming data greatly increases the computational attack surface. The SafeDocs program will focus on simplifying existing data formats and advancing the state of the art in the security of document and data format parsers. Simplification is essential to enabling automated code verification and assuring that the conditions of data validity are enforced. SafeDocs technology will enable secure documents and streaming data. ***FY 2019 Plans:*** - Develop techniques to identify, extract, and prioritize the critical elements of existing electronic documents and streaming data formats that are essential for reduced-complexity format variants. ***FY 2020 Plans:*** - Explore formal development approaches for reduced-complexity format variants for electronic documents/data and the associated processing software. - Design reduced-complexity format variants and parsers for electronic documents and streaming data. - Initiate construction of verified functionally correct, efficient parsers for syntactically complex formats currently in use. ***FY 2019 to FY 2020 Increase/Decrease Statement:***	-	11.000	14.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The FY 2020 increase reflects expanded efforts to develop reduced-complexity formats for electronic documents and streaming data and verified functionally correct, efficient parsers.			
Title: Foundational Artificial Intelligence (AI) Science ***Description:*** The Foundational Artificial Intelligence (AI) Science thrust will develop a fundamental scientific basis for understanding and quantifying performance expectations and limits of AI technologies. Current AI technologies are challenged in handling uncertainty and incompleteness of training protocols and data. This has prevented the successful integration of AI technology into many transformative DoD applications. To address these limitations the Foundational AI science thrust will focus on the development of new learning architectures that enhance AI systems' ability to handle uncertainty, reduce vulnerabilities, and improve robustness for DoD AI systems. One focus area of this thrust is the ability to embed known physics, mathematics, and other prior knowledge to improve performance of AI systems, particularly for problem sets involving incomplete, sparse and noisy data. Another focus area is the development of a model framework for quantifying performance expectations and limits of AI systems. A third focus area is the development of new tools and methodologies that enable AI approaches for accelerated molecular discovery. The technology advances achieved under the Foundational AI Science thrust will ultimately remove technical barriers to exploiting AI technologies for scientific discovery, human-AI collaboration, and other DoD relevant applications. ***FY 2020 Plans:*** - Initiate efforts to identify and develop AI architectures that make optimal use of both observational and experimental data, simulated data, and prior knowledge. - Design initial physics-based machine learning architectures, algorithms, and approaches. - Test and evaluate initial physics-based machine learning architectures, algorithms, and approaches. - Demonstrate novel AI architectures that exploit advances in Transfer Learning, One-shot Learning and Human-Aware AI. - Demonstrate the ability to quantify AI performance/robustness tradeoffs in DoD-relevant application domains. - Begin development of hardware and control software for autonomous experimental chemistry systems. - Explore automated approaches for extracting data from lab notebooks and instrumentation, refining representations, and demonstrating semi-autonomous experimentation informed by models. - Test systems on real-world problems in one or more relevant DoD domains where the behaviors are not known in advance. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.	-	-	16.500
Title: Human-Machine Symbiosis (HMS) ***Description:*** The Human-Machine Symbiosis (HMS) program will conduct basic research to enable machines to collaborate with humans as colleagues, partners, and teammates. The world is moving faster than humans can assimilate, understand, and act.	-	-	13.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
At present, we design machines to handle well-defined, high-volume or high-speed tasks, freeing humans to focus on complexity. If successful, HMS will bring forth technologies that enable machines to do more than execute pre-programmed instructions. Rather, HMS-enabled machines will: 1) understand speech; 2) extract information contained in diverse media; 3) learn, reason and apply knowledge gained through experience; 4) identify and work to fill knowledge gaps; 5) extrapolate causal phenomena to anticipate predictable outcomes; and 6) respond intelligently to new and unforeseen events. A companion Applied Research effort is funded in PE 0602303E, Project IT-04. ***FY 2020 Plans:*** - Investigate and derive performance predictions for computational agents capable of advising and guiding humans in the performance of physical tasks. - Develop computational simulations of knowledge-seeking behavior and combine these with human-machine dialog techniques that can automatically generate efficacious questions for human experts. - Evaluate alternative goal reasoning techniques to serve as the basis for curious machines that identify and fill knowledge gaps. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.			
Title: Alternative Computing	-	-	9.800
Description: The Alternative Computing thrust will explore and develop new computational primitives for modeling and simulating complex systems. Despite decades of rapid advancement in electronic computing, there remain important national security relevant challenge problems that do not lend themselves to achieving tractable solutions under size, weight, and power (SWaP) constrained conditions. For example, simulation of complex nonlinear phenomena such as turbulence, fluid flow and plasma dynamics can be challenging even using currently available high power computing resources. Building on technologies developed under the Advanced Tools for Modeling and Simulation thrust, also in this PE/Project, the goal of the Alternative Computing thrust is to develop novel architectural and algorithmic approaches to enable fast and accurate simulations for problems that are practically intractable using electronic computers. Approaches considered under this thrust include the following: (1) analog computing substrates for efficiently simulating systems governed by complex non-linear phenomena; (2) multi-functional spin-based devices for scalable, efficient neuromorphic computing; (3) computing approaches that exploit the capacity of nonlinear systems to simulate nonlinear dynamical systems; and (4) quantum enabled simulations of complex phenomena in physics, chemistry and materials. ***FY 2020 Plans:*** - Initiate efforts to determine near term applications for quantum computing in simulating complex phenomena in physics, chemistry and materials. - Investigate potential for spin-based devices to enable scalable, efficient implementation of neuromorphic computing.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Demonstrate the ability to quantify fundamental limitations of performance and scalability of quantum simulation due to factors such as decoherence, degeneracy, environmental interactions, and others. - Demonstrate proof of concept for novel analog computing substrates that outperform electronic computing in the simulation of complex non-linear phenomena. - Identify national security relevant challenge problems for quantifying speed and power efficiency advantages of analog computing substrates over electronic computing. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.			
Title: Applied Mathematics ***Description:*** The Applied Mathematics thrust will create the basic mathematics needed to support complex, multi-physics analysis ranging from uncertainty quantification to integrated, multi-system design. Focus areas of this thrust include application of geometry to challenge problems in optimization science and frameworks and advanced tools for propagating and managing uncertainty in the modeling and design of complex physical and engineering systems. ***FY 2019 Plans:*** - Advance the developed optimization tools to handle substantial complexity and make working progress towards a fully nonlinear, non-convex problem. - Demonstrate full theoretical and computational development of optimization methodologies with implementation on the real scope/scale application problem. - Initiate work on development of codes and software for the tested optimization algorithms. - Identify promising analog computing substrates for efficient simulation of complex non-linear phenomena. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.	8.489	5.276	-
Title: Lifelong Learning Machines (L2M) ***Description:*** The Lifelong Learning Machines (L2M) program will research and develop fundamentally new machine learning mechanisms, enabling machines that learn continuously as they operate. Current learning machines are fully configured in advance of deployment, meaning that they have difficulty accounting for in-the-field mission changes or for unexpected deviations in the data being processed. To overcome this limitation, L2M will pursue learning approaches inspired by biological systems, which continuously learn and improve their skills without losing previous knowledge. Areas of research will include network structures that improve performance by processing new data seen in the field, learn new tasks without forgetting previous tasks, and incorporate context into their understanding of the environment. These capabilities would impact a broad array of military	19.000	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
applications that require processing and understanding data in real-time, often have limited data sets for training, and must be deployed in environments where unpredictable events may occur. The L2M program moves to Project ES-02, Beyond Scaling Sciences, in FY 2019.			
Title: Mining and Understanding Software Enclaves (MUSE) ***Description:*** The Mining and Understanding Software Enclaves (MUSE) program developed program analyses and frameworks for improving the resilience and reliability of complex software applications at scale. MUSE applied machine learning algorithms to large software corpora to repair defects and vulnerabilities in existing software, and to create new software programs that conform to desired behaviors and specifications. Specific technical challenges included generation and analysis of persistent semantic artifacts, identification and repair of defects, and inference and synthesis of specifications. MUSE research improves the security of intelligence-related applications and enhances 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.	13.000	-	-
Title: Big Mechanism ***Description:*** The Big Mechanism program created new approaches to automate computational intelligence applicable to diverse domains such as biology, cyber, economics, social science, and intelligence. Mastering these domains requires the capability to create abstract, causal models from massive volumes of diverse data. Current modeling approaches are heavily reliant on human insight and expertise, but the complexity of these models will soon exceed the capacity for human comprehension. Big Mechanism created technologies to: extract and normalize information for incorporation in flexible knowledge bases; build reasoning engines that can infer general rules from a collection of observations; and develop knowledge synthesis techniques to create models of extreme complexity consistent with huge volumes of data. Big Mechanism applications accommodate an operator-in-the-loop to clarify ambiguities and reconcile detected inconsistencies. The program focused on cancer modeling due to the availability of experimental data. The complexity of this problem is representative of challenges facing the DoD in areas such as cyber attribution and open-source intelligence.	4.353	-	-
Title: Knowledge Representation ***Description:*** The Knowledge Representation thrust developed much-needed tools to contextualize and analyze heterogeneous scientific data, facilitating field-wide hypothesis generation and testing. This was accomplished by focusing on two key efforts: (1) the development of domain-agnostic mathematical tools for representing heterogeneous data and (2) the development of 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 included validation across multiple disparate scientific and	3.000	-	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
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.			
Accomplishments/Planned Programs Subtotals	174.658	173.629	220.824

	FY 2018	FY 2019
Congressional Add: DARPA Foundational and Applied Artificial Intelligence	-	15.000
FY 2019 Plans: - Develop approaches to build, maintain, and reason over rich models of complex systems by interpreting and exposing scientific knowledge and assumptions in existing code and documentation. - Create systems to extract scientific laws and governing equations from data and assess the adequacy of the supplied data, identifying regions where additional data would be most beneficial. - Research the computational principles and architecture of reduced-scale systems in miniaturized insect species operating with low energy that could identify new computing paradigms for improved AI with considerably reduced training times and power consumption.		
Congressional Adds Subtotals	-	15.000

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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
CYS-01: *CYBER SCIENCES*	-	44.094	12.801	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-

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. Information technologies enable important new military capabilities and drive the productivity gains essential to U.S. economic competitiveness. Meanwhile, cyber threats grow in sophistication and number, and put sensitive data, classified computer programs, mission-critical information systems, and future economic gains at risk. The basic research conducted under the Cyber Sciences project will produce breakthroughs necessary to enhance the resilience of DoD information systems to current and emerging cyber threats.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Transparent Computing	18.630	9.201	-
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 obscure linkages between security-related events, making it hard to discover attacks such as advanced persistent threats (APTs). The Transparent Computing program will create the capability to propagate security-relevant information, track complete knowledge of event provenance, 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 2019 Plans:*** - Provide a user interface with tracking and visualization of tagged traffic on the network. - Implement policy enforcement and enterprise architecture protection capabilities. - Demonstrate techniques to filter tag streams and information for relevance without sacrificing precision and accuracy. - Improve scalability of provenance graph construction, and test and evaluate performance and effectiveness. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Title: Space/Time Analysis for Cybersecurity (STAC)	15.504	3.600	-
Description: The Space/Time Analysis for Cybersecurity (STAC) program is developing techniques to detect algorithmic complexity vulnerabilities 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 cyber adversaries are now finding new ways of compromising software. Algorithmic complexity and side channel attacks are emerging as a new generation of attacks since they depend on intrinsic properties of software algorithms rather than implementation flaws.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The STAC program seeks to develop analysis tools and techniques to detect vulnerabilities to these new attacks in the software on which the U.S. government, military, and economy depend. ***FY 2019 Plans:*** - Update analysis toolset with latest versions of tools from engagements. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Title: SafeWare ***Description:*** The SafeWare program developed new code obfuscation techniques for protecting software from reverse engineering. At present, adversaries can extract sensitive information from stolen software, which could include cryptographic private keys, special inputs/failsafe modes, and proprietary algorithms. Today's state-of-the-art in software obfuscation adds junk code (loops that do nothing, renaming of variables, redundant conditions, etc.) that is not resilient against automated tools. 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 1970s. In its present form, cryptographic obfuscation incurs too much runtime overhead to be practical. The SafeWare program took this very early-stage obfuscation theory and increased its practicality and efficiency.	9.960	-	-
Accomplishments/Planned Programs Subtotals	44.094	12.801	-

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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
ES-01: *ELECTRONIC SCIENCES*	-	69.001	41.032	43.333	-	43.333	35.083	36.883	34.883	34.883	-	-

A. Mission Description and Budget Item Justification

The Electronic Sciences project is for basic exploration of electronic and optoelectronic devices, circuits, and processing concepts to meet the military's need for near real-time information gathering, transmission, and processing. In seeking to continue the phenomenal progress in microelectronics innovation that has characterized the last few decades, the project should provide DoD with new, improved, or potentially revolutionary device options for accomplishing these critical functions. The resulting technologies should help maintain knowledge of the enemy, communicate decisions based on that knowledge, and substantially improve the cost and performance of military systems. Research areas include analog, mixed signal, and photonic circuitry for communications and other applications; alternative computer architectures; and magnetic components to reduce the size of Electromagnetic (EM) and sensing systems. Other research could support field-portable electronics with reduced power requirements, ultra-high density information storage "on-a-chip", and new approaches to nanometer-scale structures, molecules, and devices.

Within this project, Beyond Scaling programs will support investigations into materials, devices, and architectures to provide continued improvements in electronics performance with or without the benefit of Moore's Law (silicon scaling). Within the next ten years, traditional scaling will start to encounter the fundamental physical limits of silicon, requiring fresh approaches to new electronic systems. Over the short term, DoD will therefore need to unleash circuit specialization in order to maximize the benefit of traditional silicon. Over the longer term, DoD and the nation will need to engage the computer, material, and mechanical sciences to explore electronics improvements through vertical circuit integration for improved computation or non-volatile memory devices that combine computation and memory. Other memory devices could also leverage an emerging understanding of the physics of magnetic states, electron spin properties, topological insulators, or phase-changing materials. Beyond Scaling programs will address fundamental exploration into each of these areas. The Beyond Scaling programs move to Project ES-02, Beyond Scaling Sciences, in FY 2019.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Magnetic Miniaturized and Monolithically Integrated Components (M3IC)	8.500	8.800	8.083
Description: The Magnetic Miniaturized and Monolithically Integrated Components (M3IC) program aims to integrate magnetic components onto semiconductor materials, improving the size and functionality of electromagnetic (EM) systems for communications, radar, and electronic warfare (EW). Current EM systems use magnetic components such as circulators, inductors, and isolators that are bulky and cannot be integrated with electronic circuitry. This limits the utility of the magnetic components as well as their ability to impact overall system performance and function. Reducing the Size, Weight, And Power (SWaP) of magnetic components and integrating them onto semiconductor chips, however, could enable broader exploitation of magnetic materials and provide new mechanisms for the control and manipulation of EM signals. For instance, tighter integration could yield smaller radar systems, higher bandwidth communication over longer ranges, improved jam resistance, and more resilient EW systems. The M3IC program is divided into three technical areas: integration of magnetic materials and systems with			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
semiconductor technology; accurate and efficient modeling of magnetic phenomena from the molecular to the component system level; and exploitation of magnetic phenomena in innovative component designs relevant to DoD EM systems. ***FY 2019 Plans:*** - Demonstrate deposition of high-quality thick magnetic films on semiconductor-compatible patterning process. - Demonstrate prototype codes with improved accuracy and efficiency and integration pathway to industry standard radio frequency (RF) circuit design tools. - Demonstrate integrated or miniaturized non-linear magnetic components leveraging the developed high quality films and novel integration approaches. ***FY 2020 Plans:*** - Deliver optimized micro-magnetic codes coupled with industry-standard RF circuit design tools. - Demonstrate integrated or miniaturized components such as circulators and frequency selective limiters incorporating new materials or integration methods, and optimized with design tools developed under the program. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects conclusion of the development effort and a shift in focus on final demonstrations.			
Title: A MEchanically Based Antenna (AMEBA)	6.000	8.000	7.900
Description: The A MEchanically Based Antenna (AMEBA) program seeks to develop efficient radio frequency (RF) transmitters operating in the Ultra-Low Frequency (ULF) and Very Low Frequency (VLF) ranges, for portable applications in underground and underwater communications. For classical antennas, the minimum antenna size for efficient transmission is related to the wavelength of the RF signal. This fundamental property prevents reducing the size of today's ULF and VLF transmitting antennas, which are up to a mile wide. Whereas traditional antennas generate electromagnetic waves by driving current through a conductive material, AMEBA takes a novel approach, mechanically moving an electrical charge or magnet to generate electromagnetic waves at ULF and VLF. This mechanical coupling provides unique advantages over traditional approaches at these frequencies, most notably greater than 1,000x reduction in antenna size. AMEBA will focus on developing both the materials and precision-controlled electromechanical systems required for an efficient transmitter system. This new capability would enable a range of applications including hard-to-jam wireless communications for use over very long distances and short-range underground and underwater RF links. Other potential applications include terrestrial navigation systems for GPS-denied environments and ground-penetrating radar for detecting unexploded ordnance, underground facilities, and tunnels. ***FY 2019 Plans:*** - Continue to improve the performance of electric and magnetic materials employed in the program.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Progressively scale mechanical systems to a larger number of elements, synchronously actuated and modulated at RF frequencies. - Demonstrate small, low frequency transmitters capable of text messaging from 10 m underwater or 30 m underground. ***FY 2020 Plans:*** - Demonstrate and deliver scaled ULF transmitters capable of text messaging from 100 m underwater and 600 m underground. - Demonstrate and deliver scaled VLF transmitters capable of communicating voice at 100 km terrestrial distances. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects minor program repricing.			
Title: SHort Range Independent Microrobotics Program (SHRIMP)	-	4.132	13.350
Description: The SHort Range Independent Microrobotics Program (SHRIMP) will develop microrobots with the ability to enter constrained disaster areas such as collapsed buildings for search and rescue operations. These sugar cubed-sized microrobots could obtain local sensing data to assist with location of injured persons or critical infrastructure failures. The capabilities of the developed microrobots will be tested through a series of Olympic-themed events at the end of the program. The primary technical developments needed are in the efficiency, robustness, and control of millimeter-scale actuators, which allow the robots to move using new materials, processing, and sensor integration techniques, and in the power and energy capacity of batteries, which provide the power required for the microrobot to move and sense stimuli. Complete platforms will require access controls for Controlled Unclassified Information (CUI). Successful execution of the SHRIMP program will advance the micro-robotics field, allowing for practical robots to assist in disaster relief efforts in environments for which traditional robotics cannot efficiently operate due to their larger size. A companion applied research effort is funded in PE 0602716E, Project ELT-01. ***FY 2019 Plans:*** - Initiate development of high force, high efficiency actuator materials for microrobotic platforms. - Initiate development of integrated multi-mode power solutions for microrobotic platforms. ***FY 2020 Plans:*** - Demonstrate actuator materials meeting program defined metrics for size, weight, and actuation force. - Demonstrate integrated power systems and batteries meeting program defined metrics for size, weight, volume, and power related performance. - Initiate development of high work density, actuator mechanisms for microrobotic platforms. - Initiate development of improved integrated multi-mode power solutions with emphasis on smaller size and performance across varied temperatures. ***FY 2019 to FY 2020 Increase/Decrease Statement:***			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The FY 2020 increase reflects the program shifting from initial development to demonstration of actuator materials, integrated power systems, and batteries.			
Title: Atomic-Photonic Integration (A-PhI)	-	5.000	14.000
Description: The Atomic-Photonic Integration (A-PhI) program, building on technology developed in the Direct On-Chip Digital Optical Synthesis (DODOS) program, aims to reduce the complexity of atomic clocks and gyroscopes by using integrated photonics for Position, Navigation, and Timing (PNT) applications. A-PhI will demonstrate that a compact photonic integrated chip can replace the optical assembly for trapped atomic gyroscopes and clocks without degrading the performance of the device. PNT is a critical resource for all DoD missions such as communications, navigation, reconnaissance, and electronic warfare. While PNT needs are usually met by using the Global Positioning System, GPS signals are vulnerable to a variety of disruption modalities and a fallback from GPS is essential. Currently, in the absence of GPS, tactical grade clocks and tactical/navigation grade Inertial Measurement Units can provide GPS-like accuracy for the short term. However, longer-term GPS independent strategies are still desirable. A-PhI will enable long-term GPS independence and enable PNT accuracy better than GPS for short durations. ***FY 2019 Plans:*** - Develop preliminary architectures for trapped atom gyroscopes. - Design low phase noise oscillators compatible with the A-PhI performance metrics. - Design, fabricate and characterize preliminary components of a photonic integrated chip for the trapped atom clock. ***FY 2020 Plans:*** - Perform a laboratory demonstration of a trapped atom gyroscope. - Demonstrate and characterize performance of a low phase noise oscillator. - Demonstrate a photonic integrated chip capable of atom trapping and cooling compatible with proposed clock architecture. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects a shift from preliminary design to fabrication and technology demonstration.			
Title: High power Amplifier using Vacuum electronics for Overmatch Capability (HAVOC)	2.000	3.000	-
Description: The High power Amplifier using Vacuum electronics for Overmatch Capability (HAVOC) program seeks to develop compact Radio Frequency (RF) signal amplifiers for air, ground, and ship-based communications, sensing, and radar systems. HAVOC amplifiers would enable these systems to access the high-frequency millimeter-wave portion of the Electromagnetic (EM) spectrum, facilitating increased range and other performance improvements. Today, the effectiveness of combat operations across all domains increasingly depends on DoD's ability to control and exploit the EM spectrum and to deny its use to adversaries. However, the proliferation of inexpensive commercial RF sources has made the EM spectrum crowded			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
and contested, challenging our spectrum dominance. Operating at higher frequencies, such as the millimeter-wave, helps DoD to overcome these issues and offers numerous tactical advantages such as high data-rate communications and high resolution and sensitivity for radar and sensors. HAVOC will fund basic research in vacuum electronics to improve understanding of the various phenomena governing 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 2019 Plans:*** - Demonstrate high-current-density and long life cathodes based on understanding gained from processing and material structure investigations. - Demonstrate wideband and high power beam-wave interaction structures meeting Phase 3 metrics. - Demonstrate high current-density cathodes meeting Phase 3 metrics. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects completion of the basic research effort.			
Title: Precise Robust Inertial Guidance for Munitions (PRIGM)	4.500	4.400	-
Description: The Precise Robust Inertial Guidance for Munitions (PRIGM) program aims to identify, investigate, and demonstrate inertial sensor technologies for Positioning, Navigation, and Timing (PNT) in GPS-denied environments. When GPS is not available, these inertial sensors can provide autonomous PNT information. The program will exploit recent advances in integrating photonic (light-manipulating) components into electronics and in employing Microelectromechanical Systems (MEMS) as high-performance inertial sensors for use in extreme environments. Whereas conventional MEMS inertial sensors can suffer from inaccuracies due to factors such as temperature sensitivity, new photonics-based PNT techniques have demonstrated the ability to mitigate these inaccuracies. PRIGM will focus on two areas. By 2020, it aims to develop and transition a Navigation-Grade Inertial Measurement Unit (NGIMU), a state-of-the-art MEMS device, to DoD platforms. By 2030, it aims to develop Advanced Inertial MEMS Sensors (AIMS) that can provide gun-hard, high-bandwidth, high dynamic range navigation for GPS-free munitions. These advances should enable navigation applications, such as smart munitions, that require low-cost, size, weight, and power inertial sensors with high bandwidth, precision, and shock tolerance. PRIGM will advance state-of-the-art MEMS gyros from TRL-3 devices to a TRL-6 transition platform, eventually enabling the Service Labs to perform TRL-7 field demonstrations. Applied research efforts are funded in PE 0602716E, Project ELT-01, and advanced technology development for the program is budgeted in PE 0603739E, Project MT-15. ***FY 2019 Plans:*** - Package all component technology, evaluate the performance of new materials and integration techniques across ultra-high shock loads, and measure long-term inertial sensor bias stability.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Demonstrate inertial sensor survival and operation through laboratory-representative launch events. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects completion of the basic research effort.			
Title: Signal Processing at RF (SPAR) ***Description:*** The Signal Processing at RF (SPAR) program will investigate advanced analog components to process radio frequency (RF) signals for communications, radar, and electronic warfare applications. Today, electronic components are limited in their ability to distinguish between two or more signals operating at the same frequency when one signal is strong enough to jam the others. The jamming signal, in this case, saturates the receiver electronics much like loud music drowns out a quiet conversation. By using advancements in new semiconductor materials, processing, and novel signal interaction mechanisms, SPAR components will be able to pick out friendly RF signals from both intentional and unintentional jamming signals, even when those signals sit on top of one another in frequency. This capability would enable a range of new applications including communications in contested battlefield RF environments, jamming the RF spectrum while maintaining communication, and full-duplex radio communication. Other potential applications include equipping mobile radios with SPAR-enabled front ends for simultaneous jam-resistant two-way communication and electronic warfare. ***FY 2019 Plans:*** - Design Phase 3 RF signal processing components with DoD communications grade performance capable of rejecting uncooperative in-band jamming by 100x and cooperative self-interference by 1,000,000x. - Fabricate and integrate the components developed during Phase 2 into a system-level design that extends Simultaneous Transmit and Receive (STAR) capability to Commercial, Off The Shelf (COTS) transceiver technology. - Perform field measurements on developed STAR system to demonstrate simultaneous bidirectional voice communications over 1 km capable of rejecting uncooperative in-band jamming by 30x and cooperative self-interference by 10,000x while maintaining communications integrity. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.	7.001	7.700	-
Title: Direct On-Chip Digital Optical Synthesis (DODOS) ***Description:*** The Direct On-chip Digital Optical Synthesis (DODOS) program investigated high-performance photonic components for a compact, robust, and highly-accurate optical frequency synthesizer suited to various mission-critical DoD applications. Frequency synthesis and accurate control of radiofrequency and microwave radiation is the enabling technology for radar, satellite and terrestrial communications, positioning and navigation technology, and many other core DoD capabilities. Frequency synthesis and control of light or optical waves, however, has been constrained to laboratory experiments due to	2.000	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
the size, fragility, and cost of optical frequency synthesizers. DODOS leveraged recent developments in the field of integrated photonics to enable the development of ubiquitous, low-cost optical frequency synthesizers. The program led to disruptive DoD capabilities, including high-bandwidth optical communications, higher performance Light Detection And Ranging (LiDAR), portable high-accuracy atomic clocks, and high-resolution detection of chemical/biological threats at a distance. Applied research for this program is funded within PE 0602716E, Project ELT-01.			
Title: Joint University Microelectronics Program (JUMP) ***Description:*** The Joint University Microelectronics Program (JUMP) is a government-industry joint research program to explore computing, sensing, communication, and data storage innovations for applications beyond the 2030 horizon. The program recognizes that the densely interconnected microsystems of the future will be built through the use of groundbreaking materials, revolutionary devices, advanced architectures, and unconventional computing. JUMP will therefore sponsor academic research teams focused on related key technology areas that will impact future DoD capabilities and national security. The JUMP program will not only push fundamental technology research but also establish long-range microelectronic research themes with greater emphasis on end-application and systems-level computation. By discovering the science underlying new technologies and overcoming engineering challenges, JUMP will enable DoD applications to exploit the entire electromagnetic spectrum from radio frequency (RF) to terahertz (THz) and to employ both distributed and centralized computing with embedded intelligence and memory. The JUMP program moves to Project ES-02, Beyond Scaling Sciences, in FY 2019.	18.000	-	-
Title: Beyond Scaling - Materials ***Description:*** The Beyond Scaling - Materials program will investigate new materials to support next-generation logic and memory components. Historically, the DoD provided leadership in shaping the electronics field through research in semiconductor materials, circuits, and processors. However, as DoD focuses on military-specific components and commercial investments eschew the semiconductor space, U.S. fundamental electronics research is stagnant just as an inflection point in Moore's Law (silicon scaling) is about to occur. The Beyond Scaling - Materials program will pursue potential enhancements in electronics that do not rely on Moore's Law, including research not only into new materials but also into the implications of those materials at the device, algorithm, and packaging levels. These basic explorations include: novel mechanisms for computation based on inherent material properties, unique architectures leveraging new components, and new methods to accelerate the identification and utilization of emerging materials. The Beyond Scaling - Materials program moves to ES-02, Beyond Scaling Sciences, in FY 2019. Applied research for this program is funded within PE 0602716E, Project ELT-02.	14.000	-	-
Title: Beyond Scaling - Architectures and Designs ***Description:*** The Beyond Scaling - Architectures and Design program will investigate the design of application-specific circuit architectures that ensure continued improvements in electronics performance with or without the benefit of continued scaling	7.000	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
in silicon transistors (Moore's Law). Currently, improvements in electronics largely depend on a regular reduction in the size of silicon components. As Moore's Law slows and the nation loses the benefit of free, exponential improvements in electronics performance, DoD will need to maximize the benefits of available silicon technologies through circuit specialization. This program will investigate the potential for lowering the barriers to designing specialized circuits. Approaches include the use of machine learning and automated design tools to program specialized hardware blocks, integrate them into existing designs, and deploy them in complex systems. Further research would also develop tools to create exact representations of physical hardware. Advances under this program will support a new DoD capability to create specialized hardware and provide benefits by improving electronics systems that do not depend on continued rapid improvements in silicon transistors. The Beyond Scaling - Architectures and Design program moves to ES-02, Beyond Scaling Sciences, in FY 2019. Applied research for this program is funded within PE 0602716E, Project ELT-02.			
Accomplishments/Planned Programs Subtotals	69.001	41.032	43.333

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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / *DEFENSE RESEARCH SCIENCES*	Project (Number/Name) ES-02 / *BEYOND SCALING SCIENCES*	

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
ES-02: *BEYOND SCALING SCIENCES*	-	0.000	51.100	47.000	-	47.000	43.800	38.700	53.290	53.290	-	-

A. Mission Description and Budget Item Justification

The Beyond Scaling Sciences project will support investigations into materials, devices, and architectures to provide continued improvements in electronics performance with or without the benefit of Moore's Law (silicon scaling). Within the next ten years, traditional scaling will start to encounter the fundamental physical limits of silicon, requiring fresh approaches to new electronic systems. Over the short term, DoD will therefore need to unleash circuit specialization in order to maximize the benefit of traditional silicon. Over the longer term, DoD and the nation will need to engage the computer, material, and mechanical sciences to explore electronics improvements through new non-volatile memory devices that combine computation, memory, and new automated design tools using machine learning. Other memory devices could also leverage an emerging understanding of the physics of magnetic states, electron spin properties, topological insulators, or phase-changing materials. Beyond Scaling programs will address fundamental exploration into each of these areas.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Beyond Scaling - Materials	-	11.000	7.000
Description: The Beyond Scaling - Materials program will investigate new materials to support next-generation logic and memory components. Historically, the DoD provided leadership in shaping the electronics field through research in semiconductor materials, circuits, and processors. However, as DoD focuses on military-specific components and commercial investments eschew the semiconductor space, U.S. fundamental electronics research is stagnant just as an inflection point in Moore's Law (silicon scaling) is about to occur. The Beyond Scaling - Materials program will pursue potential enhancements in electronics that do not rely on Moore's Law, including research not only into new materials but also into the implications of those materials at the device, algorithm, and packaging levels. These basic explorations include, novel mechanisms for computation based on inherent material properties, new methods to accelerate the identification and utilization of emerging materials, and innovative processes to vertically integrate these materials with others to realize superior computational mechanisms. The Beyond Scaling - Materials program moved from Project ES-01, Electronic Sciences, in FY 2019. Applied research for this program is funded within PE 0602716E, Project ELT-02.			
FY 2019 Plans: - Demonstrate the basic material properties which would allow for greatly increasing the amount of computational throughput. - Demonstrate the performance and physics of unconventional components that enable new circuit topologies and architectures. - Complete analysis and preliminary architectural design that integrates compute elements with high-performance memory components.			
FY 2020 Plans:			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-02 / *BEYOND SCALING SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Identify preliminary DoD-relevant benchmark algorithms. - Complete detailed analysis using hardware emulation/simulation in process showing performance benefits of technology approach. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects a shift in focus on analysis and benchmarking of components developed in FY 2019.			
Title: Beyond Scaling - Architectures and Designs	-	6.000	5.800
Description: The Beyond Scaling - Architectures and Design program will investigate application-specific circuit architectures that ensure continued improvements in electronics performance with or without the benefit of continued scaling in silicon transistors (Moore's Law). Currently, improvements in electronics largely depend on a regular reduction in the size of silicon components. As Moore's Law slows and the nation loses the benefit of free, exponential improvements in electronics performance, DoD will need to maximize the benefits of available silicon technologies through circuit specialization. This program will investigate the potential for lowering the barriers to designing specialized circuits. Approaches include the use of machine learning and automated design tools to program specialized hardware blocks, integrate them into existing designs, and deploy them in complex systems. Further research would also develop tools to create exact representations of physical hardware. Advances under this program will support a new DoD capability to create specialized hardware and provide benefits by improving electronics systems that do not depend on continued rapid improvements in silicon transistors. The Beyond Scaling - Architectures and Designs program moved from Project ES-01, Electronic Sciences, in FY 2019. Applied research for this program is funded within PE 0602716E, Project ELT-02. ***FY 2019 Plans:*** - Develop a cloud-based computer infrastructure and implement open source algorithms that will increase the quality of individual components and decrease design time. - Demonstrate the application of machine learning to a chip layout process flow to determine the tradeoffs between accuracy, automation and turn-around time. ***FY 2020 Plans:*** - Deliver open source software for physical layout of digital circuits verified against a set of open source benchmark circuits that will fully automate mixed signal System-On-Chip, package, and printed circuit board layout. - Demonstrate rapid, automated generation of digital circuits at multiple technology nodes using an open source software platform. ***FY 2019 to FY 2020 Increase/Decrease Statement:***			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-02 / *BEYOND SCALING SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The FY 2020 decrease reflects minor program repricing.			
Title: Lifelong Learning Machines (L2M)	-	16.100	16.200
Description: The Lifelong Learning Machines (L2M) program will research and develop fundamentally new machine learning mechanisms, enabling machines that learn continuously as they operate. Current learning machines are fully configured in advance of deployment, meaning that they have difficulty accounting for in-the-field mission changes or for unexpected deviations in the data being processed. To overcome this limitation, L2M will pursue learning approaches inspired by biological systems, which continuously learn and improve their skills without losing previous knowledge. Areas of research will include network structures that improve performance by processing new data seen in the field, learn new tasks without forgetting previous tasks, and incorporate context into their understanding of the environment. These capabilities would impact a broad array of military applications that require processing and understanding data in real-time, often have limited data sets for training, and must be deployed in environments where unpredictable events may occur. The L2M program moved from Project CCS-02, Math and Computer Sciences, in FY 2019. ***FY 2019 Plans:*** - Demonstrate continual learning by determining the ability of artificial intelligence (AI) systems to improve performance while the systems operate, using their current experience as training data. - Design algorithms that can use previous information and generalize it to never before seen situations. - Invent a method that allows a machine learning system to balance adaptability to handling new environments while keeping some previous knowledge that may be important in later stages. - Develop plans for how new biological mechanisms will be proven and measured in software, including preliminary specifications of test data. - Generate common test data of interest to the government and distribute to performers for validating lifelong learning core capabilities. ***FY 2020 Plans:*** - Translate first sets of insights from biological experiments into machine learning algorithms, and show that developed algorithms improve lifelong learning capabilities. - Begin porting and testing of the first set of algorithms on the L2M specified test cases. - Demonstrate first lifelong learning system with all five L2M core capabilities using test cases, and show that combining multiple L2M capabilities into a single system provides significant improvement over single focus systems. - Complete demonstrations of working systems by each use case. ***FY 2019 to FY 2020 Increase/Decrease Statement:***			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-02 / *BEYOND SCALING SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The FY 2020 increase reflects minor program repricing.			
Title: Joint University Microelectronics Program (JUMP)	-	18.000	18.000
Description: The Joint University Microelectronics Program (JUMP) is a government-industry joint research program to explore computing, sensing, communication, and data storage innovations for applications beyond the 2030 horizon. The program recognizes that the densely interconnected microsystems of the future will be built through the use of groundbreaking materials, revolutionary devices, advanced architectures, and unconventional computing. JUMP will therefore sponsor academic research teams focused on related key technology areas that will impact future DoD capabilities and national security. The JUMP program will not only push fundamental technology research but also establish long-range microelectronic research themes with greater emphasis on end-application and systems-level computation. By discovering the science underlying new technologies and overcoming engineering challenges, JUMP will enable DoD applications to exploit the entire electromagnetic spectrum from radio frequency (RF) to terahertz (THz) and to employ both distributed and centralized computing with embedded intelligence and memory. The JUMP program moved from Project ES-01, Electronic Sciences, in FY 2019. ***FY 2019 Plans:*** - Expand university research teams to add newly identified technical projects. - Develop emerging materials, power efficient radio frequency (RF), terahertz (THz), digital, and storage devices prototype. - Establish novel distributed and centralized computing architectures and subsystems for efficient information extraction, processing, and autonomous control applications. ***FY 2020 Plans:*** - Benchmark emerging materials, power efficient RF, THz, digital, and storage devices prototype. - Demonstrate prototypes of novel distributed and centralized computing architectures and subsystems for efficient information extraction, processing, and autonomous control applications. - Identify new research directions and amend new projects to the JUMP university research portfolio.			
Accomplishments/Planned Programs Subtotals	-	51.100	47.000

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-02 / *BEYOND SCALING SCIENCES*

E. Performance Metrics

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

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
MS-01: *MATERIALS SCIENCES*	-	65.675	77.919	63.412	-	63.412	65.436	62.255	60.138	50.138	-	-

A. Mission Description and Budget Item Justification

The Materials Sciences project provides the fundamental research that underpins the design, development, assembly, and optimization of advanced materials, devices, and systems for DoD applications in areas such as robust diagnostics and therapeutics, novel energetic materials, and complex hybrid systems.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Molecular Systems and Materials Assembly	18.290	19.700	11.000

Description: The Molecular Systems and Materials Assembly thrust is exploring new approaches for the synthesis, assembly, and characterization of molecules and materials from the atomic to the product scale. Ultimately, materials and methods developed in this thrust will support a wide range of DoD applications that span therapeutics, energetics, computation and next generation optical materials. Specific approaches include non-traditional synthetic approaches such as the use of extreme pressure and/or temperature conditions, engineering and controlling atomic-scale processing routes for designer microstructures, and the synthesis and rapid screening of many molecules to more quickly identify those with desired functions and/or properties. Efforts in this thrust also include assembly of these and other materials, such as subwavelength engineered shapes, into micro-to-macro-scale objects and devices, exploration of molecules for information storage and processing, and fundamental studies of the properties and function of these molecular ensembles and systems.

FY 2019 Plans:

- Demonstrate creation of complex hierarchical structures with nanoscale features and properties.
- Develop methods for the scale-up of nano- and micro-assembly techniques.
- Demonstrate approaches for reading molecular data, including random access.
- Validate molecular processing approaches against relevant computational problems.
- Initiate integration of storage and processing approaches to develop a molecular computing concept.
- Activate, formulate, and test the performance of six new candidate energetic molecules that were synthetically inaccessible to the DoD energetics community in prior years.
- Demonstrate feasibility of synthesis, activation, testing, and redesign cycle in which government labs provide design recommendations without sharing sensitive information.

FY 2020 Plans:

- Define limitations associated with scale-up of nano- and micro-assembly processes.
- Demonstrate operational molecular computing system by linking storage and processing components and execute processing approaches directly on molecular data.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Identify and quantify advantages of molecular computing over conventional computing and storage methods. - Characterize and mitigate error sources in storage and processing approaches and demonstrate repeatability of storage and processing approaches. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects completion of the thrusts to develop non-traditional synthesis and rapid screening of many molecules to more quickly identify those with desired functions and/or properties and assembly of these and other materials, such as subwavelength engineered shapes, into micro-to-macro-scale objects and devices.			
Title: Fundamental Limits ***Description:*** Understanding the fundamental limits (i.e., achievable boundaries) of scientific principles, processes and technologies is critical to better anticipate technological surprise for our adversaries and ourselves. This thrust explores boundaries across fields such as physics, chemistry, mathematics, biology, and engineering to address critical questions for national security. This thrust is addressing foundational theory and approaches that include, for example, the fundamental limitations of optical technologies, potential implications for basic biology on national security, and the ability for modeling and simulation to provide a better understanding of complex systems. ***FY 2019 Plans:*** - Design and optimize centimeter (cm) scale optical systems based on engineered materials. - Fabricate and test cm scale engineered material optical components. - Determine if selected biological systems use electromagnetic signaling to purposefully communicate. - Compare the accuracy and precision of theoretical signaling predictions with experimental measurements within and among biological systems. - Quantify information channel capacity and characteristics pending any newly discovered communications pathways in selected biological systems. - Develop design tools for "meta-atom or meta-molecule" building blocks and structures that can be used to create new material responses to electromagnetic radiation. - Investigate breaking metamolecule symmetry and Lorentz reciprocity to create new material designs. - Develop predictive, parametric models for materials for frequency mixing. - Establish penetration/range/resolution trade space using low frequency electromagnetic waves for imaging. - Demonstrate the possibility of high-resolution imaging in the near field using very low frequency (VLF) detector arrays. ***FY 2020 Plans:*** - Integrate and demonstrate optical systems and architectures based on engineered materials.	18.000	25.219	31.400

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Extend capability of modeling tools to simulate cm-scale devices and confirm performance with characterization of cm-scale engineered materials. - Investigate the possibility of influencing electromagnetic biological sensing or regulation as a result of any newly discovered biological communications channels. - Demonstrate basic technical capabilities needed to examine electromagnetic, or electromagnetically facilitated, biological signaling channels. - Develop experimental methods and setups to test predictive, parametric models of nascent light-matter interactions under investigation. - Analyze experimental results of nascent light-matter interactions and provide input back to parametric models to further optimize and refine the modeling framework. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects a shift from design to development and demonstration.			
Title: Non-Equilibrium Materials	8.935	18.000	21.012
Description: The Non-Equilibrium Materials thrust will explore materials and materials structures that acquire novel properties when driven far from equilibrium. Work in this thrust will examine the physical underpinnings and applications of these systems in areas of interest to the DoD, including next generation electronics, high-performance computing, and sensing. Efforts will include the development of topologically protected excitations in electronic materials and fundamental studies of exotic quantum states of matter in periodically driven solid-state systems. ***FY 2019 Plans:*** - Establish the presence of topological excitations with size <10 nanometer (nm) at room temperature in a material system. - Demonstrate long-term preservation of coherence in a topologically protected qubit. - Design protocols for enhancing the lifetime of quantum coherence in a large quantum system. - Develop techniques to probe the properties of material systems driven far from equilibrium. - Design system for the demonstration of enhanced lifetime of a periodically driven correlated electron material. - Validate the existence of novel phases of matter in systems driven out of equilibrium. ***FY 2020 Plans:*** - Demonstrate fast current-induced motion of topological excitations. - Develop prototype devices for topologically protected memory. - Implement gate operations in topologically protected qubits. - Experimentally demonstrate the enhancement of coherence time in a large quantum system.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Demonstrate extended lifetime for a correlated electron phase. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects additional demonstrations of the applications of non-equilibrium materials.			
Title: Basic Photon Science ***Description:*** The Basic Photon Science thrust is examining the fundamental science of photons and their interactions in integrated devices for potential DoD-applications such as communications, signal processing, spectroscopic sensing and imaging. One focus area is development of novel, chip-scale optical frequency comb sources and associated technologies for spectroscopic sensing, identification, and quantification of multiple trace materials in spectrally cluttered backgrounds. Additional research will explore development of a complex theoretical framework for maximum information extraction from complex scenes to guide development of new imaging technologies. Work in this thrust will establish the first-principles limits of photon detector performance in a variety of detector technologies to enable better, more sensitive detectors. ***FY 2019 Plans:*** - Compare the fundamental properties of new proof-of-concept detector designs with device performance. - Determine which individual state of the art metrics (efficiency, jitter, bandwidth, and photon number count) are improved by an order of magnitude. - Determine which detector designs result in several state of the art metrics (efficiency, jitter, bandwidth, photon number count) being improved simultaneously by an order of magnitude. - Finalize prototype detector designs that are optimized for specified DoD needs. - Refine viable components and algorithms for reconstructing individual aspects of a 3D scene from a single viewpoint. - Combine non-line of sight approaches capable of creating an image of individual visible and hidden aspects of a scene from a single viewpoint into an integrated system. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.	20.450	15.000	-
Accomplishments/Planned Programs Subtotals	65.675	77.919	63.412

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** MS-01 / *MATERIALS SCIENCES*

E. Performance Metrics

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

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
TRS-01: *TRANSFORMATIVE SCIENCES*	-	50.020	51.199	57.715	-	57.715	50.321	50.488	30.681	24.576	-	-

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, and manufacturing. 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 or threaten National Security. Specific research in this project will investigate technologies to enable detection of novel threat agents (e.g., bacterial pathogens) and maintain warfighter health, as well as create innovative materials of interest to the military (e.g., self-healing materials).

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Biological Complexity (BioCom)	9.632	11.940	9.950

Description: The Biological Complexity (BioCom) program 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 improve warfighter readiness and resilience. 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. Applications range from infectious disease mitigation or prevention, maintaining warfighter health, to leveraging biological systems for optimal production of therapeutics.

FY 2019 Plans:
- Develop theoretical and computational approaches to improve design of biological control systems in complex settings.
- Characterize performance and verify specifications of measurement technologies for assessing biological control.
- Build multiple, integrated system-level controllers within complex biological systems.
- Expand the library of well-characterized biological parts relevant to controlling complex biological systems.
- Establish processes for feedback control of mammalian cellular behaviors to enable robust responses to stimuli in the form of growth and/or differentiation.

FY 2020 Plans:
- Demonstrate solutions that counter pathogens and antibiotic resistance, regulate inflammation from Traumatic Brain Injury (TBI), and maintain a healthy gut.
- Deliver new experimental tools and algorithms to engineer control of biological system behavior that is robust to perturbation.
- Demonstrate real time characterization of cell and molecular responses to control algorithms.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Establish the limits on reproducibility of performance of biological control systems. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects an assessment to focus on demonstrations related to warfighter health.			
Title: Social Simulation (SocialSim) ***Description:*** The Social Simulation (SocialSim) program is developing a computational capability to simulate the spread and evolution of information in the online environment. The global information environment is radically changing how and at what rate information spreads and evolves, and both nation-state and sub-state actors are incorporating messaging into their operations to great advantage. Existing approaches for understanding online information spread and evolution are largely based on specialized exercises that take considerable time to orchestrate and execute, and have limited accuracy. SocialSim aims to enable a deeper and more quantitative understanding of adversaries' messaging campaigns and their likely outcomes, as well as exploration of potential responses. ***FY 2019 Plans:*** - Test the capability to simulate online information evolution. - Evaluate the performance of social simulations of diverse scenarios in a single online environment. - Extend the underlying models and mechanisms to simulate the spread and evolution of information in multiple interconnected online environments. ***FY 2020 Plans:*** - Evaluate the performance of the extended models and mechanisms across multiple interconnected online environments. - Integrate the multiple models and mechanisms into a prototype and leverage ensemble modeling and meta-modeling techniques to support performance-based application of models. - Demonstrate the capability to accurately represent online social phenomena, such as recurrent cascades of information, and to quantify the effects of small, persistent groups of information disseminators. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects minor program repricing.	12.451	13.014	12.952
Title: Engineered Living Materials (ELM) ***Description:*** The Engineered Living Materials (ELM) program will pursue new approaches to engineer complex, multi-cellular systems for enhanced capabilities and functional materials to improve military infrastructure design and logistics. 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	15.584	12.955	9.350

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
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. Advances in this program will impact military approaches to infrastructure design in austere environments as well as established methods for manufacture and maintenance of military platforms (e.g., tanks, planes, ships). ***FY 2019 Plans:*** - Assess the potential for engineered living materials to respond to damage. - Develop methods to control growth in engineered living materials. - Investigate approaches to propagate external signals over long distances in engineered living materials. - Demonstrate stability over relevant time periods in programmed multi-dimensional shapes. ***FY 2020 Plans:*** - Demonstrate at least two-fold improvements in rate of growth and maintenance of size. - Demonstrate engineered cell-cell interactions to organize and maintain the density/spacing of patterns. - Demonstrate increased strength, scaling, and robustness of materials in a built environment. - Demonstrate controlled healing in response to damage of advanced materials. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects a reduction of development efforts and a focus on final demonstration.			
Title: Biology for Security (BIOSEC)	6.653	13.290	15.847
Description: Based on initial research conducted under the Biological Robustness in Complex Settings (BRICS) program, the Biology for Security (BIOSEC) program seeks to investigate novel approaches to address the DoD need for rapid detection of unknown and/or emerging biological threats from state actors or violent extremist organizations (VEOs). This program will investigate approaches for identifying pathogens based on specific behaviors, or phenotypes, such as niche finding or cell toxicity. Unlike current methods, which rely on a priori knowledge of the pathogen and cannot detect or otherwise analyze unknown threats, this approach will handle scenarios involving engineered or undiscovered bacterial pathogens that do not have known hallmarks. Advances in this area will produce a completely new capability to assess the emergence of pathogens and to detect pathogens that have been specifically engineered to evade detection by traditional methods. Resulting systems may be used to alert deployed military personnel operating around the world to new biothreats, or in response to a U.S.-based discovery, outbreak, or pandemic. ***FY 2019 Plans:*** - Develop assays to rapidly screen organisms or biological systems for traits and mechanisms of interest. - Identify genes and pathways associated with complex biological traits.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Establish the potential for natural or synthetic biological systems as biological threat detectors. ***FY 2020 Plans:*** - Demonstrate unbiased high-throughput isolation of microbes from complex samples. - Develop strategies for the maintenance and growth of all bacterial types from complex environmental samples. - Demonstrate effective processes for phenotyping small numbers of bacteria for the three principal classes of pathogenic traits: niche finding, attacking a membrane, and self-defense. - Implement data fusion and remedial algorithms for machine learning and modeling of pathogenicity. - Demonstrate isolation and bioinformatics protocols on complex samples that show the potential for integration into a unified platform. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects increased system complexity and integration of demonstrated sampling and interrogation efforts.			
Title: Native Bioelectronic Interfaces ***Description:*** The Native Bioelectronic Interfaces effort will address the DoD need for improving warfighter recovery from injury by developing technologies that can accelerate the restoration and repair of complex tissues. This program will develop approaches that combine high-resolution biosensors to track the healing process in real-time with bioactuators to stimulate restoration where and when needed. The primary challenge to achieving this is the lack of a closed-loop interface that can manipulate highly complex signaling pathways in wounds and the developmental interdependencies that scale from cell to tissue. The program will develop new methods to convert dense multi-modal information into the body's native repair processes, and will leverage artificial intelligence to guide the delivery of the signals necessary for healing. Advances from this program will produce bioactuators that can release diverse stimuli with high spatial and temporal resolution, and biosensors that provide the requisite in situ measurement to guide the healing process. ***FY 2020 Plans:*** - Identify effective stimuli for directing growth, development, and repair. - Identify critical physiological changes and biomarkers that can report on cell growth and differentiation. - Develop first set of algorithms that can deliver preliminary intervention strategies. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.	-	-	9.616
Title: Living Foundries ***Description:*** The goal of the Living Foundries program was 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	3.000	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
and adapt to changing environments and self-repair, biology represents one of the most powerful manufacturing platforms known. Living Foundries developed 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 provided game-changing manufacturing paradigms for the DoD, enabling adaptable, on-demand production of critical and high-value molecules. Living Foundries developed tools to simplify, abstract, and standardize the biological production pathway optimization process. Additionally, Living Foundries identified the fundamental design rules that govern the construction and organization of underlying genetic elements in the production pathways. Research thrusts included development of 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. This resulted in rapid design, construction, implementation, and testing of complex, higher-order genetic networks with programmable functionality. Applied research for this program was budgeted in PE 0602715E, Project MBT-02.			
Title: Biological Robustness in Complex Settings (BRICS) ***Description:*** The Biological Robustness in Complex Settings (BRICS) program leveraged 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 facilitated design and biological production of new chemicals and materials, sensing capabilities, therapeutics, and numerous other applications. This rapidly developing technological capability opened 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 focused on understanding the underlying principles for engineering robust and safe microbes and microbial communities that perform as designed over the long-term. This program also had applied research efforts funded in PE 0602715E, Project MBT-02.	2.700	-	-
Accomplishments/Planned Programs Subtotals	50.020	51.199	57.715

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** TRS-01 / *TRANSFORMATIVE SCIENCES*

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 2020 Defense Advanced Research Projects Agency	Date: March 2019
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*

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	42.129	46.575	54.122	-	54.122	51.337	48.516	47.456	47.456	-	-
MED-01: *BASIC OPERATIONAL MEDICAL SCIENCE*	-	42.129	46.575	54.122	-	54.122	51.337	48.516	47.456	47.456	-	-

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; exploring methods to slow damage from pathological infection or traumatic injury; and leveraging 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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	43.126	47.825	44.771	-	44.771
Current President's Budget	42.129	46.575	54.122	-	54.122
Total Adjustments	-0.997	-1.250	9.351	-	9.351
• Congressional General Reductions	0.000	-6.250			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	5.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	0.600	0.000			
• SBIR/STTR Transfer	-1.597	0.000			
• TotalOtherAdjustments	-	-	9.351	-	9.351

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2018	FY 2019
Project: MED-01: *BASIC OPERATIONAL MEDICAL SCIENCE*		
Congressional Add: *TBI Treatment for Blast Injuries*	-	5.000

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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 2018	FY 2019
Congressional Add Subtotals for Project: MED-01	-	5.000
Congressional Add Totals for all Projects	-	5.000

Change Summary Explanation

FY 2018: Decrease reflects SBIR/STTR transfer offset by reprogrammings.
FY 2019: Decrease reflects Congressional adjustments.
FY 2020: Increase reflects the initiation of the Improved Interventions program.

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Outpacing Infectious Disease	16.976	14.190	13.894

Description: Military readiness and national security depend on the health and well-being of military service members. Unfortunately, today's antivirals and vaccines are often circumvented by fast-mutating viruses that evolve to develop drug resistance. Military service members often deploy to areas with such diseases that require new protective measures to maintain readiness. The Outpacing Infectious Disease thrust will investigate fundamental methods for using biology as a technology to create adaptive therapeutic response mechanisms to outpace viral diseases such as enabling co-evolution and co-transmission of newly developed therapeutics to ultimately outcompete the pathogen. Key advances expected from this research include identifying methods to discover and develop new classes of dynamic therapeutics for fast-mutating viruses. This approach represents a significant departure from conventional 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 diseases that impact military readiness and pose a National Security risk as a potential pandemic.

FY 2019 Plans:
- Apply predictive mathematical models to optimize therapeutic interfering particle (TIP) packaging and mobilization for increased efficacy.
- Investigate factors that determine TIP long-term stability.
- Optimize TIPs for selected viruses and evaluate in relevant animal models of infection.
- Optimize TIP production, purification, and scale-up.

FY 2020 Plans:
- Assess optimal route, dose, and timing of treatment for selected virus TIP candidates in relevant animal models.
- Determine the broad spectrum efficacy against multiple viral strains.
- Assess TIP transmission dynamics in animal models.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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 2018	FY 2019	FY 2020
- Prepare regulatory package for first-in-human pre-clinical trial for TIPs. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects minor program repricing.			
Title: Preventing the Emergence of Disease (PED) ***Description:*** Many emerging infectious disease outbreaks have origins in animal reservoirs and occur in areas where DoD personnel are deployed, putting them at high risk of endemic and emerging diseases. The Preventing the Emergence of Disease (PED) program will investigate how animal pathogens are transmitted to humans and explore novel approaches to prevent these events. Tools such as detailed molecular analysis and bioinformatics will be leveraged. Researchers will develop models to quantify the probability of pathogen disease transmission from animals to humans. Promising intervention approaches will be developed to prevent viral species jumps from animal reservoirs to humans. Predicting such jumps is a key capability to mitigating outbreaks originating in animal reservoirs. ***FY 2019 Plans:*** - Develop initial risk models of species jumps for selected viruses using biosurveillance data, geographic location, and animal-animal and/or animal-human interactions. - Develop preliminary mathematical models that predict parameters responsible for virus species jump and models that link viral genetics to transmission dynamics. - Establish experimental testbeds to validate model predictions and to test preemptive approaches. - Determine virus competence (ability to infect) in different vector species. - Initiate in vitro testing of preemptive approaches for suppressing viral jump. ***FY 2020 Plans:*** - Refine mathematical models of virus dynamics within and between two host species, and initiate validation with data from the field. - Integrate virus transmission dynamics, environmental data, and viral fitness metrics into spillover risk model for selected viruses. - Demonstrate proof-of-concept preemptive approaches for suppressing virus jump from one species to another in a relevant animal model. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects minor program repricing.	10.789	12.040	12.598
Title: Early Battlefield Interventions (EBI) ***Description:*** Based on initial research conducted under the Analysis and Adaptation of Human Resilience program, the Early Battlefield Interventions (EBI) program will explore new methods to slow and limit damage caused by acute trauma and infection	4.500	10.965	13.348

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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 2018	FY 2019	FY 2020
often suffered by our warfighters under far-forward conditions. Research efforts will apply advances in molecular and cellular biology, cell signaling, and biomaterials to develop new tools to alter the time course of pathological processes associated with infection and tissue damage. This tactic is a departure from traditional therapeutic approaches that seek to control symptoms associated with active infections or innate physiological responses to tissue trauma. Advances in this area may be applied to the creation of both prophylactic and therapeutic medical countermeasures to forward-deployed service members. ***FY 2019 Plans:*** - Develop chemical biology methods to reversibly slow biological processes in cells. - Test interventions in human cells or enzymes. - Begin to investigate delivery methods to successfully implement interventions in multi-cellular systems. - Initiate software development for molecular design. ***FY 2020 Plans:*** - Characterize the molecular mechanisms for reversibly slowing biological processes in cells. - Begin to test novel interventions to reversibly slow biochemical processes in multicellular biological systems (e.g., organoids, tissues). - Evaluate protein stabilization induced by interventions in multicellular biological systems. - Characterize intervention formulations to enhance cell penetration and reversibility. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects concurrent tests conducted at the cellular and multicellular level and the evaluation and characterization of the results.			
Title: Improved Interventions	-	-	14.282
Description: The Improved Interventions program seeks to develop novel pharmacological interventions to quickly and holistically optimize the performance of the healthy warfighter. The status quo for pharmacological intervention is one drug, one target, which often has many undesirable side effects. This program will create a platform to develop pharmacological interventions capable of modulating multiple targets within biological systems of the body, which will reduce side effects and promote safety. Research will focus on the integration of novel bioinformatics approaches, high-content physiological model systems, and new bio-orthogonal chemical synthesis methods to treat the system in order to achieve desired physiological effects. Progress in this area will lead to new pharmacological discovery and design principles that will lead to products that can be used to augment physical fitness training and maintenance for military populations. The Improved Interventions program builds upon the genomic and physiological analyses conducted under the Analysis and Adaptation of Human Resilience program. ***FY 2020 Plans:***			

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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 2018	FY 2019	FY 2020
- Generate preliminary datasets of proteins involved in a complex physiological process. - Begin to build computational tools that model complex physiological processes. - Begin development of informatics pipeline to predict targets regardless of prior knowledge. - Analyze biochemical processes associated with proteins of unknown function. - Identify chemical synthesis methods to build novel small molecules to target any protein or combination of proteins in the human proteome. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** FY 2020 increase reflects program initiation.			
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. Research efforts 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 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. Research efforts within this program may enable discovery of novel methods to optimize human health against infectious diseases caused by multi-drug resistant pathogens. ***FY 2019 Plans:*** - Analyze the tolerance response across different animal species, infection models and those discovered in animals using open source human data sets. - Validate tolerance mechanisms in resilient animal models. - Test tolerance-based interventions in susceptible animal models. - Identify strategies for further developing interventions to improve warfighter health and performance. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.	9.864	4.380	-
Accomplishments/Planned Programs Subtotals	42.129	41.575	54.122

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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*

	FY 2018	FY 2019
Congressional Add: TBI Treatment for Blast Injuries	-	5.000
FY 2019 Plans: Conduct research in TBI treatment for blast injuries.		
Congressional Adds Subtotals	-	5.000

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.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	88.962	101.300	97.771	-	97.771	123.570	120.783	122.687	134.997	-	-
BT-01: *BIOMEDICAL TECHNOLOGY*	-	88.962	101.300	97.771	-	97.771	123.570	120.783	122.687	134.997	-	-

A. Mission Description and Budget Item Justification

This Biomedical Technology Program Element focuses on applied research for medical related technology, information, processes, materials, systems, and devices. Successful battlefield medical and neural interface technologies developed within this Program Element address a broad range of DoD challenges to ensure warfighter readiness, including both resilience to infectious disease and neurotechnology for improved warfighter performance. To maintain warfighter health, battlefield medical technologies research in this project will investigate disease forecasting, detection, and therapeutic response. Example programs include a predictive platform for forecasting disease outbreak, identification of early infection biomarkers to diagnose and prevent widespread infection in-theater, new methods to rapidly develop medical countermeasures in response to an emerging biothreat, and in-theater manufacturing capabilities for field-relevant pharmaceuticals to reduce the logistical burden and infrastructure requirements. To improve warfighter performance, this project will develop new neural architectures and data processing algorithms to interface the nervous system with multiple devices, enabling control of robotic prosthetic-limb technology. Additionally, advanced evidence-based techniques will be developed to supplement warfighter healthcare and the diagnosis of post-traumatic stress disorder (PTSD) and traumatic brain injury (TBI).

B. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	109.360	101.300	130.831	-	130.831
Current President's Budget	88.962	101.300	97.771	-	97.771
Total Adjustments	-20.398	0.000	-33.060	-	-33.060
• Congressional General Reductions	-15.000	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	-1.398	0.000			
• SBIR/STTR Transfer	-4.000	0.000			
• TotalOtherAdjustments	-	-	-33.060	-	-33.060

Change Summary Explanation

FY 2018: Decrease reflects Congressional reduction, SBIR/STTR transfer and reprogrammings.
FY 2019: N/A
FY 2020: Decrease reflects completion of the Neuro-Adaptive Technology and Enhanced Monitoring of Health and Disease programs in FY 2019.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602115E / *BIOMEDICAL TECHNOLOGY*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Restoration of Auditory and Visual Function After Injury*	15.900	16.485	13.676
Description: *Formerly Performance Optimization in Complex Environments The Restoration of Auditory and Visual Function After Injury program is developing neurotechnology to mitigate the effects of physical injury to the auditory and visual systems of military personnel. Research is also focusing on understanding various forms of sensing and actuation to improve outcomes and how biofeedback over time can alter human brain function. Technologies developed through this program will provide foundational neural interface technology for restoring lost capability, improving situational awareness, and enhancing cognitive and physical effectiveness. ***FY 2019 Plans:*** - Validate system designs and safety methods against standard regulatory practices. - Demonstrate large-scale neural read and write capabilities using a fully integrated system. - Collect data for the development and refinement of neural decoding and encoding algorithms. - Prepare regulatory documents for Food and Drug Administration approval. ***FY 2020 Plans:*** - Validate system designs for prototyping and manufacture. - Harden size, weight, and power of complete integrated system. - Perform in vivo demonstration of the fully integrated input-output platform. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects completion of research activities to conduct final system validation and demonstration.			
Title: Neural Signal Interfaces and Applications (NSIA)	8.140	15.895	19.125
Description: As part of their daily duties, many military personnel must handle large volumes of data and interact with complex systems. These tasks could be made less difficult with advanced neurotechnology platforms, but all such devices currently require invasive surgery to implement. The Neural Signal Interfaces and Applications (NSIA) program will develop non-invasive neurotechnologies able to interface with the nervous system with high resolution and precision without surgery. NSIA will utilize recent advances to transduce neural signals through tissue. Resulting technologies will facilitate standard human-machine interfaces for improved workload balance between man and machine. ***FY 2019 Plans:*** - Finalize system level design to optimize power usage. - Engineer prototypes of neural interface subcomponents and neural transducers. - Assess neural read and write subcomponents and neural transducers in vitro.			

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602115E / *BIOMEDICAL TECHNOLOGY*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Verify and validate the safety, resolution, and stability of subcomponents. ***FY 2020 Plans:*** - Integrate neural read and write subcomponents. - Optimize neural transducer delivery plan. - Initiate experiments toward achieving regulatory approval for clinical studies. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects integration of all subcomponents into final prototype device as well as demonstration in animal models.			
Title: Pandemic Prevention	17.100	24.985	24.450
Description: Military personnel are deployed all over the world for traditional operations, and are often specifically called upon in response to emerging or re-emerging disease outbreaks with pandemic potential (e.g., Ebola). In both instances, the DoD needs effective countermeasures to protect its deployed forces and maintain warfighter readiness. The Pandemic Prevention program is focusing on novel methods to rapidly accelerate countermeasure discovery, pre-clinical testing, and manufacturing. This program seeks to advance and integrate newly developed approaches including bioinformatics assessment of genetic sequencing and nucleic acid-based vaccines and to address technology bottlenecks associated with each stage of medical countermeasure development. Additional research will investigate new methods improving the manufacturability, distribution, and delivery of novel therapeutics. Pandemic Prevention will enable an integrated therapeutic development platform that leverages state-of-the-art technologies to prevent disease outbreaks. ***FY 2019 Plans:*** - Demonstrate the ability to rapidly discover and mature antibodies against viral infections. - Establish gene-encoded antibody delivery methods in animal models. - Demonstrate protection from pathogen challenge in animal models. - Conduct, in under 90 days, preliminary demonstration of integrated technologies identifying, maturing, and delivering a gene-encoded antibody to provide protection against viral challenge in animal models. - Initiate development and testing of nucleic acid constructs to encode for multiple antibody targets. ***FY 2020 Plans:*** - Investigate the kinetic profile of gene-encoded antibodies in large animal models. - Conduct, in under 60 days, a demonstration of integrated technologies identifying, maturing, and delivering a gene-encoded antibody to provide protection against viral challenge in animal models. - Demonstrate, in less than 20 days, the ability to identify a highly potent antibody, targeting a viral pathogen. - File an Investigational New Drug (IND) application with the Food and Drug Administration for a gene-encoded antibody product.			

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602115E / *BIOMEDICAL TECHNOLOGY*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Initiate a Phase I human clinical safety study of a gene-encoded antibody. - Initiate IND enabling studies for a nucleic acid construct encoding multiple antibodies. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects minor program repricing.			
Title: Forensic Indicators of Threat Exposure (FITE) ***Description:*** Based on initial research conducted under the Enhanced Monitoring of Health and Disease program, the Forensic Indicators of Threat Exposure (FITE) program is developing a field-deployable resource for indicators of an individual's exposure history to Weapons of Mass Destruction (WMD) and WMD precursors. FITE will investigate the ability to characterize epigenetic signatures in an individual's genome caused by specific exposures. The program will create the framework for modular technology capable of performing forensic analysis using epigenetic information to provide high specificity of the type of exposure and when it occurred. This novel capability could serve as a field-forward forensic tool for use by the DoD to assist in chemical, biological, radiological, and nuclear (CBRN) threat detection and response. ***FY 2019 Plans:*** - Identify exposure-specific epigenetic marks that reflect WMD or WMD precursor exposure events. - Create bioinformatics algorithms to decode and characterize differences in the complex epigenetic marks associated with each exposure event. - Validate sensitivity and specificity of the forensic and diagnostics signatures when combined with detection algorithms. - Develop a platform prototype to integrate multiple molecular analysis techniques and perform forensic and diagnostic assessment of exposure. - Initiate research to understand connections between genotype and phenotype to inform impact on human performance. ***FY 2020 Plans:*** - Generate epigenetic signatures that reveal temporal resolution of exposure events from WMD or WMD precursor exposure events. - Refine bioinformatics algorithms for increased sensitivity and specificity of the epigenetic signatures. - Perform pressure tests to assess the ability to distinguish viral from bacterial signatures in clinical samples. - Select molecular analysis methods for integration into the deployable platform. - Finalize selection of module components and complete system design for deployable platform prototype. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects minor program repricing.	4.750	13.995	14.404
Title: Prosthetic Hand Proprioception & Touch Interfaces (HAPTIX)	15.074	14.985	9.149

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602115E / *BIOMEDICAL TECHNOLOGY*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Description: Wounded warriors often suffer from neural injury due to spinal cord injury or amputations. Military personnel 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 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. Research in this area will also address similar interface technologies with other nerve pathways such as the spinal cord. The anticipated transition partner is the Army. ***FY 2019 Plans:*** - Obtain regulatory approval for HAPTIX technology. - Conduct novel outcome metric testing on HAPTIX amputee participants. - Initiate take-home studies of the HAPTIX system. - Initiate algorithm development, hardware manufacturing, and system integration for spinal cord injury. ***FY 2020 Plans:*** - Complete take-home studies utilizing HAPTIX technology and sensorized prosthetic limbs. - Complete surgical implants and perform proof of concept of a percutaneous implementation for spinal cord injury. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects completion of take-home studies.			
Title: Improved Personnel Placement (IPP) ***Description:*** Building upon work initiated under the Forensic Indicators of Threat Exposure (FITE) program, the Improved Personnel Placement (IPP) program will aim to improve force lethality and overmatch by identifying and training candidates for specialized military positions in order to maximize performance and minimize attrition. IPP will study the relationships between genotype and phenotype to identify unique physical, cognitive, and behavioral traits associated with elite military specialties. The program will develop technology to sense real time gene activity associated with those identified performance traits and leverage this information to provide warfighters with training options to maximize their potential. Maximizing an individual's biological aptitude will enable placement choices that facilitate readiness and resilience for the DoD. ***FY 2020 Plans:*** - Compare attributes of specialized warfighters to identify biomarkers associated with specialized military roles. - Design in silico and in vitro testbeds to emulate extreme training or performance conditions.	-	-	16.967

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602115E / *BIOMEDICAL TECHNOLOGY*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Build data analysis approaches that can integrate proteomic, genomic, and epigenomic results to characterize elite performers. - Develop initial real-time indicators for gene expression. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.			
Title: Neuro-Adaptive Technology ***Description:*** The Neuro-Adaptive Technology program is exploring and developing 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 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 program 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 2019 Plans:*** - Utilize clinical data to further refine biomarkers, computational models, and stimulation paradigms for closed-loop modulation of psychiatric or neurologic conditions. - Integrate approaches targeting psychiatric or neurologic conditions with complementary biomarkers, neural targets, and computational models. - Demonstrate use of the prototype neural device in a clinical setting to reduce relevant psychiatric or neurologic symptoms through real-time, closed-loop, biomarker-driven stimulation. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.	12.210	10.955	-
Title: Enhanced Monitoring of Health and Disease ***Description:*** The Enhanced Monitoring of Health and Disease program is improving military health and force readiness by leveraging advanced data collection methods and prognostic capabilities to predict changes in health and spread of infectious disease from the individual to the population scale. While new technology platforms have enhanced our ability to respond to	5.460	4.000	-

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602115E / *BIOMEDICAL TECHNOLOGY*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
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, such as in a barracks or in a confined environment (e.g., submarine). Research in this program 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 program 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 2019 Plans:*** - Initiate additional clinical cohort studies that represent secondary transmission events for biomarker and contagiousness measurements. - Evaluate performance of the minimal set of biomarkers for the ability to predict contagiousness outcomes against the clinical cohort data. - Complete development of a prognostic assay that predicts contagiousness using the minimal set of biomarkers. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** FY 2020 decrease reflects program completion.			
Title: Restoration of Brain Function Following Trauma ***Description:*** The Restoration of Brain Function Following Trauma program exploited recent advances in the understanding and modeling of brain activity and organization to develop approaches to treat traumatic brain injury (TBI). Critical to success was the ability to detect and quantify functional 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 also developed neural interface hardware for monitoring and modulating neural activity responsible for successful memory formation in a human clinical population. The ultimate goal was identification of efficacious therapeutic approaches that could bypass and/or recover the neural functions underlying memory, which are often disrupted as a consequence of TBI.	7.828	-	-
Title: Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT) ***Description:*** The overarching goal of the Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT) program was 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 focused 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 developed methods to transiently deliver nucleic acids for vaccines and	2.500	-	-

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602115E / *BIOMEDICAL TECHNOLOGY*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
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 also focused on advanced development of key elements for simple-to-operate diagnostic devices.			
Accomplishments/Planned Programs Subtotals	88.962	101.300	97.771

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.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	379.578	404.967	442.556	-	442.556	435.746	461.923	494.810	506.254	-	-
IT-02: *HIGH PRODUCTIVITY, HIGH-PERFORMANCE RESPONSIVE ARCHITECTURES*	-	48.006	52.184	22.538	-	22.538	39.630	55.730	65.730	65.730	-	-
IT-03: *CYBER SECURITY*	-	262.375	255.919	258.850	-	258.850	229.254	235.940	247.159	251.603	-	-
IT-04: *ARTIFICIAL INTELLIGENCE AND HUMAN-MACHINE SYMBIOSIS*	-	69.197	96.864	161.168	-	161.168	166.862	170.253	181.921	188.921	-	-

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 focuses on developing the computer hardware and associated software technologies required for future computationally- and data-intensive national security applications. Powerful new approaches are needed to manage the rapid growth in available sensor data, to leverage advances in machine learning and artificial intelligence, and to maintain the security of DoD information systems.

The Cyber Security project is developing the computing, networking, and cyber security technologies required to protect DoD, U.S. government, and U.S. civilian information, information infrastructure, and mission-critical information systems. Information technologies enable important new military capabilities and drive the productivity gains essential to U.S. industry.

The Artificial Intelligence and Human-Machine Symbiosis project develops technologies to enable machines to function not only as tools that facilitate human action but as trusted partners to human operators. Of particular interest are systems that can understand human speech and extract information contained in diverse media; answer questions, reach conclusions, and propose explanations; and learn, reason and apply knowledge gained through experience to respond intelligently to new and unforeseen events. Enabling computing systems with such human-like intelligence is now of critical importance because the tempo of military operations in emerging domains exceeds that at which unaided humans can orient, understand, and act.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide I* BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602303E *I INFORMATION & COMMUNICATIONS TECHNOLOGY*

B. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	392.784	395.317	376.946	-	376.946
Current President's Budget	379.578	404.967	442.556	-	442.556
Total Adjustments	-13.206	9.650	65.610	-	65.610
• Congressional General Reductions	0.000	-15.350			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	25.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	0.000	0.000			
• SBIR/STTR Transfer	-13.206	0.000			
• TotalOtherAdjustments	-	-	65.610	-	65.610

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2018	FY 2019
Project: IT-04: *ARTIFICIAL INTELLIGENCE AND HUMAN-MACHINE SYMBIOSIS*		
Congressional Add: *DARPA Foundational and Applied Artificial Intelligence*	-	25.000
Congressional Add Subtotals for Project: IT-04	-	25.000
Congressional Add Totals for all Projects	-	25.000

Change Summary Explanation

FY 2018: Decrease reflects SBIR/STTR transfer.

FY 2019: Increase reflects Congressional adjustments.

FY 2020: Increase reflects new start artificial intelligence programs in the Artificial Intelligence and Human-Machine Symbiosis project.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
IT-02: *HIGH PRODUCTIVITY, HIGH-PERFORMANCE RESPONSIVE ARCHITECTURES*	-	48.006	52.184	22.538	-	22.538	39.630	55.730	65.730	65.730	-	-

A. Mission Description and Budget Item Justification

The High Productivity, High-Performance Responsive Architectures project focuses on developing the computer hardware and associated software technologies required for future computationally- and data-intensive national security applications. Powerful new approaches are needed to manage the rapid growth in available sensor data, to leverage advances in machine learning and artificial intelligence, and to maintain the security of DoD information systems. The project therefore aims not only to create larger computing platforms but also to efficiently extract information out of large and chaotic data sets with embedded and low-size, weight, and power systems. Advances in these areas could allow DoD electronic systems to collaboratively manage scarce resources, such as the electromagnetic spectrum, and to adapt to new requirements and situations. Further, the resulting technologies, by being accessible to a wide range of application developers, should help develop new, sustainable computing systems for a broad spectrum of scientific and engineering applications.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Spectrum Collaboration Challenge (SC2)	18.000	25.184	2.000
Description: The Spectrum Collaboration Challenge (SC2) program seeks to catalyze the development of systems, called Collaborative Intelligent Radios (CIRs) that intelligently share and optimize wireless spectrum usage without prior knowledge of each other's operating characteristics. SC2 will address the increasing demand for and reliance on unfettered wireless access. Today, assured access to the wireless spectrum involves restricting particular types of radios and radio operators to certain sets of fixed, pre-determined frequencies. Although this spectrum allocation approach helps ensure different radio signals do not interfere with each other, it is inherently inefficient and vulnerable to attack. First, allocated portions of the spectrum can remain unused or underutilized. Second, adversaries can easily characterize static spectrum allocations, identifying which ones to exploit or attack. SC2 will address this challenge by leveraging artificial intelligence and machine learning to optimize use of the spectrum in real-time. In particular, SC2 participants will be challenged to develop techniques that allow collaboration among dissimilar communications technologies. SC2 will conduct two preliminary competitions and one championship event over three years. The resulting technology will define a new class of radio systems that efficiently thrive in the absence of pre-planned spectrum.			
FY 2019 Plans: - Hold a second competition, to take place on the custom-built competition testbed. - Identify transition partner for the testbed post competition final event.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Develop final competition event execution plan. ***FY 2020 Plans:*** - Execute a live championship event with an international audience of 1,000+ at Mobile World Congress Americas. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The decrease in FY 2020 reflects program completion.			
Title: RF Machine Learning Systems (RFMLS) ***Description:*** The RF Machine Learning Systems (RFMLS) program is addressing the performance limitations of conventional radio frequency (RF) systems such as radar, signals intelligence, electronic warfare, and communications. The performance of future RF systems in the DoD will be defined by their ability to adapt and respond to their environment in real-time. We currently lack both the algorithms and computational power to manage the volume of data and complexity of decision-making that will be required. RFMLS technology will develop machine learning techniques that are able to help manage this complexity by, for example, recognizing specific emitters or detecting anomalies in a cluttered environment. The objective of the RFMLS program is to both develop these foundational technologies and to apply them to relevant DoD systems. ***FY 2019 Plans:*** - Evaluate integratability of machine learning algorithms and architectures with candidate DoD RF hardware systems. - Complete first phase development of machine learning algorithms and architectures for the four challenge problems. - Test preliminary performance of solutions for the four challenge problems. - Complete development of an RF hardware system to host field testing and demonstrations. ***FY 2020 Plans:*** - Complete final phase development of machine learning algorithms and architectures for the four challenge problems. - Create test and demonstration plan for final open-air demonstration of RFMLS algorithms. - Begin integration of machine learning solutions into an RF hardware system to host field testing and demonstrations. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The decrease in FY 2020 reflects completing the process of demonstrating machine learning algorithms on a test platform.	10.000	27.000	20.538
Title: Hierarchical Identify Verify Exploit (HIVE) ***Description:*** The Hierarchical Identify Verify Exploit (HIVE) program is pursuing new hardware architectures and algorithms for improving the efficiency of graph and sparse data analytics. When developing operationally significant intelligence, human analysts today are forced to reduce the scope of the problems that they can address and the tempo of their analyses due to the limitations of currently deployed hardware. Because of these limitations the amount of information gathered is quickly outstripping	18.006	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
the human ability to review, process, fuse, and interpret. To resolve this challenge, HIVE seeks to leverage improvements in computational efficiency to augment the analyst's ability to integrate large streams of data. The program will investigate advances in chip architecture and data analytics algorithms that can allow machines to infer meaning out of data based on the information needs of the warfighter. Program success would therefore enable the warfighter to understand far more of the battlespace in real time. The HIVE program moves to PE 0602716E/ Project ELT-02 in FY 2019.			
Title: Electronic Globalization ***Description:*** The Electronic Globalization effort aimed to develop advanced capabilities for validating the function of digital, analog, and mixed-signal integrated circuits (IC) given limited design specifications. These ICs are critical to nearly all military systems. Globalization and rapid growth in the commercial electronics industry have limited DoD's ability to influence and regulate IC fabrication. DoD today accounts for a relatively small portion of the overall IC market and the vast majority of IC manufacturing capacity lies overseas. As a result, parts acquired for DoD systems may not meet the stated specifications for performance and reliability. Electronic Globalization pursued the technologies required to address this and other risks to DoD IC's, such as reverse engineering, counterfeiting, and the theft of U.S. intellectual property. The effort supported the development of key risk-reduction techniques including advanced imaging and computational methods for identifying an IC's functional elements.	2.000	-	-
Accomplishments/Planned Programs Subtotals	48.006	52.184	22.538

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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	Project (Number/Name) IT-03 / *CYBER SECURITY*	

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
IT-03: *CYBER SECURITY*	-	262.375	255.919	258.850	-	258.850	229.254	235.940	247.159	251.603	-	-

A. Mission Description and Budget Item Justification

The Cyber Security project is developing the computing, networking, and cyber security technologies required to protect DoD, U.S. government, and U.S. civilian information, information infrastructure, and mission-critical information systems. Information technologies enable important new military capabilities and drive the productivity gains essential to U.S. industry. Meanwhile, cyber threats grow in sophistication and number, and put sensitive data, classified computer programs, mission-critical information systems, and U.S. economic competitiveness at risk. The technologies developed in this project will enhance the resilience of information systems to current and emerging cyber threats; enable broad situational awareness of the cyber domain; and provide the basis for accurate, calibrated, and safe cyber response.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Cyber-Hunting at Scale (CHASE)	16.344	21.800	23.600
Description: The Cyber-Hunting at Scale (CHASE) program is developing data-driven tools for real-time cyber threat detection, characterization, and protection within enterprise-scale networks. U.S. computer networks are continually under attack, but at present no tools exist to efficiently extract the right data from the right device at the right time to analyze these attacks for DoD-scale information networks. For example, analysis of an in-memory exploit would require detailed data from a few devices, while analysis of a global botnet attack would require summary data from a great many devices. CHASE is developing novel algorithms and analysis tools to dynamically collect data from across the network, actively hunt for advanced threats that evade routine security measures, and automatically disseminate protective measures that bolster the collective cyber defense posture.			
FY 2019 Plans: - Refine algorithms to process raw and summary cyber data, and construct feature sets for indicators of adversary activity such as credential misuse, data exfiltration, and lateral movement. - Demonstrate improved detection and identification capabilities using closed loop approaches for managing data collection, transmission, and retention. - Perform initial test and evaluation of the most promising cyber threat detection and protective measures through adversarial use cases drawn from real-world datasets including raw packet capture (PCAP), host system log, and netflow data. - Demonstrate distributed algorithms to enhance enterprise-scale cyber situational awareness via tests using real-world data.			
FY 2020 Plans: - Integrate threat detection, threat characterization, and data planning components, and demonstrate integrated data management feedback loops in real networks. - Evaluate effectiveness of threat detection and data planning components using operational datasets from transition partners. - Integrate foundational protective measures for adversarial actions such as data exfiltration and lateral movement.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-03 / *CYBER SECURITY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Demonstrate global analysis methods and foundational protective measures on distributed enterprise networks. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase is the result of development work continuing, integration work increasing, and expanded demonstration and evaluation efforts on distributed enterprise networks.			
Title: Harnessing Autonomy for Countering Cyber-adversary Systems (HACCS) ***Description:*** The Harnessing Autonomy for Countering Cyber-adversary Systems (HACCS) program is developing safe and reliable autonomous software agents that can neutralize botnet implants and similar large-scale malware. HACCS is developing technologies to (1) identify and characterize botnet-conscripted networks of devices to determine the types of devices and the software services running on them with sufficient precision to infer the presence of known vulnerabilities; (2) generate software exploits for a large number of known vulnerabilities that can be used to establish initial presence in each botnet-conscripted network without disrupting system functionality; and (3) create high-assurance software agents that autonomously navigate within botnet-conscripted networks, identify botnet implants, and curtail their ability to operate while minimizing side effects to systems and infrastructure. HACCS technologies will enable U.S. agencies possessing the appropriate authorities to safely conduct Internet-scale counter-botnet operations. ***FY 2019 Plans:*** - Enhance botnet-tracking algorithms by developing and incorporating techniques to detect stealthy and covert command-and-control protocols. - Scale vulnerability discovery and exploit generation techniques to complex software running on real operating systems. - Collaborate with transition partners to test counter-botnet autonomous agents in synthetic environments, and demonstrate the capability to characterize botnet-conscripted networks. ***FY 2020 Plans:*** - Expand vulnerability discovery techniques for additional classes of software bugs. - Evaluate botnet-tracking algorithms for detecting stealthy and covert command-and-control protocols. - Evaluate autonomous agent behavior in contained environments. - Collaborate with transition partners to determine how counter-botnet technologies may be integrated into existing architectures. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase is the result of continued counter-botnet technology development and prototype integration work, and expanded demonstrations on synthetic environments in collaboration with transition partners.	15.248	19.000	22.500
Title: Rapid Attack Detection, Isolation and Characterization Systems (RADICS)	35.386	27.310	22.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-03 / *CYBER SECURITY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020

Description: The Rapid Attack Detection, Isolation and Characterization Systems (RADICS) program is developing automated systems to enable a black start recovery of the U.S. power grid amidst a cyber attack on the energy sector's critical infrastructure. This approach will enable skilled cyber and power engineers to rapidly restore electrical service after an attack that challenges the recovery capabilities of the impacted organizations (e.g., utilities, balancing authorities, independent system operators, bulk power markets). The potential for a cyber-enabled attack on the U.S. power grid is a national security issue, as the ability of the military to deploy and project force is dependent on the effective and efficient functioning of civilian logistics and supply systems. RADICS will develop technologies to monitor heterogeneous distributed networks, detect anomalies that require rapid assessment, isolate compromised system elements, establish secure emergency communications networks, characterize attacks, and detect sensor spoofing. RADICS technology development is coordinated with and will transition to U.S. government elements responsible for defense of critical infrastructure.

FY 2019 Plans:
- Develop robust capability for grid physics anomaly and Supervisory Control and Data Acquisition (SCADA) spoofing detection.
- Develop approaches to augment and optimize the use of available communications links to create ad hoc secure emergency communications networks under conditions of substantial uncertainty.
- Develop capability for rapid localization, isolation, and characterization of cyber weapons targeting a wide range of industrial control system (ICS) devices and networks, and develop automated approaches to support cyber first responders in remediation efforts.
- Demonstrate capabilities to maintain and expand situational awareness in the aftermath of a cyber-enabled attack on the power grid.
- Conduct operationally-backed exercises to evaluate readiness for transition of RADICS tools, engage with potential transition partner personnel to enable them to use the tools in these exercises, and gather feedback on tool effectiveness.

FY 2020 Plans:
- Refine capabilities to detect, correlate, and report grid physics anomalies at scale across multiple disparate utilities.
- Develop communications prototype optimizing the use of available communication channels in a contested environment to coordinate cyber first responder and utility actions.
- Develop prototypes to quickly perform cyber forensic analysis and restore operational functionality of ICS/SCADA equipment for continued operations.
- Prototype capabilities to maintain and expand situational awareness and a trusted operational picture.
- Conduct capstone exercise demonstrating operational impact of prototypes, and prepare tools for technology transition.

FY 2019 to FY 2020 Increase/Decrease Statement:

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-03 / *CYBER SECURITY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The FY 2020 decrease reflects ramping down of development and integration of prototypes for rapid recovery of the power grid from a cyber attack, continuation of exercises to establish technology operational readiness, and technology transition.			
Title: Enhanced Attribution ***Description:*** The Enhanced Attribution program is developing technologies to associate the malicious actions of cyber adversaries to individual operators, and to publicly reveal these actions without compromising sources and methods. The program focuses on new approaches for identifying malicious cyber operators, analyzing their software tools and actions, and confirming this information with commercial and public sources of data. As the attribution techniques are developed and show promise, they will provide the basis for new cyber capabilities such as indications and warning of adversary cyber actions. These technologies will be implemented in tools for evaluation by potential transition partners. ***FY 2019 Plans:*** - Develop and demonstrate scalable algorithms for querying cyber data across multiple databases. - Demonstrate automated narrative generation of adversary cyber operator activities. - Develop metrics that quantify risks to sources and methods in alternative attribution narratives. - Collaborate with transition partners to evaluate attribution technologies in operationally relevant scenarios. ***FY 2020 Plans:*** - Integrate event extraction techniques into an attribution fusion platform. - Develop and evaluate predictive analytic algorithms for anticipating adversary actions across a cyber campaign. - Develop and evaluate adversary pattern matching algorithms for discovering previously unknown campaigns. - Support transition partners in their evaluation of the attribution and narrative generation technologies in realistic scenarios. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects minor program repricing.	21.214	20.830	21.500
Title: Dispersed Computing ***Description:*** The Dispersed Computing program is developing techniques to distribute computing tasks across network computing elements to enable more efficient utilization of enterprise and Internet-based storage, processing, and networking resources. At present, enterprises and Internet-based information technology service providers are increasingly adopting the cloud model, with data storage and computer processing concentrated in large data centers, which brings economies of scale and cost savings to storage and processing, but creates problems for the network and for latency-sensitive applications due to the need to backhaul data to (often distant) data centers for processing. The Dispersed Computing program will develop a dispersed computing architecture that results in more efficient utilization of storage, processing, and networking resources. A key enabler is the recent introduction by vendors of network elements that can be dual-purposed as computational elements. These dual-	17.000	18.000	20.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
purposed network-compute elements make it possible to eliminate bottlenecks/chokepoints and to mitigate impossible backhaul requirements by opportunistically moving code to data given network conditions and available network-compute elements. With Dispersed Computing technology, the network becomes the cloud and computation is performed where it is most efficient to do so. ***FY 2019 Plans:*** - Implement integrated prototype network-compute elements that incorporate dispersed computation algorithms and programmable protocol stack functionality. - Develop a user interface that enables operators to understand how the dispersed network computation elements are performing as a unified system on applications of interest. - Stand up a large-scale testbed to simulate real-world environments, test integrated prototypes at scale, and conduct demonstrations of prototypes. ***FY 2020 Plans:*** - Develop automated mechanisms for redistributing workloads across dispersed network computation elements to achieve reliable and near-optimal performance even in the presence of dynamic failures and impairments. - Extend the user interface to provide operators with fine-grained visibility into the workloads being handled by the dispersed network computation elements on applications of interest. - Evaluate integrated prototype network-compute elements and demonstrate prototypes to Defense Information Systems Agency and commercial network providers. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects continued development of the technologies and software prototypes for distributing workloads to network-compute elements, and expanded testing and demonstration for potential transition partners.			
Title: Computers and Humans Exploring Software Security (CHESS)*	7.500	13.000	18.900
Description: *Formerly Symbiotic Cyber Operations The Computers and Humans Exploring Software Security (CHESS) program is developing technologies to enable computers and humans to reason collaboratively over software artifacts, such as source code and compiled binaries, with the goal of finding vulnerabilities more rapidly and accurately than unaided human operators. CHESS envisions a future in which high-intensity cyber operations are conducted by computer-human teams. CHESS capabilities will be designed for use by humans of varying skill levels, even those with no previous cyber experience or relevant domain knowledge. Achieving the necessary scale and timelines in vulnerability discovery will require innovative combinations of automated program analysis techniques with support for			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
advanced computer-human collaboration. Combining human-generated insight into the vulnerability discovery process with the speed and scale of computational analysis will be a critical enabler for U.S. operational cyber superiority. ***FY 2019 Plans:*** - Develop instrumentation to capture and analyze the process by which humans reason over software to provide a basis for developing new forms of highly effective communication and information sharing between computers and humans. - Create contextually sensitive cyber reasoning techniques to address vulnerability classes that currently require human insight. - Generate representations of information gaps revealed by cyber reasoning systems to facilitate resolution by humans of varying skill levels. ***FY 2020 Plans:*** - Develop techniques for emitting a proof of vulnerability to confirm existence of a vulnerability, and for generating a non-disruptive, specific patch to neutralize the vulnerability. - Implement emerging vulnerability discovery techniques in an initial proof-of-concept computer-human software reasoning system. - Assess computer-human vulnerability discovery techniques on a synthetic vulnerability challenge corpus representative of complex software packages. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase is the result of development work accelerating, additional work to integrate technologies in a proof-of-concept computer-human software reasoning system, and initial performance assessments on a synthetic challenge corpus.			
Title: Configuration Security	6.930	16.230	18.000
Description: The Configuration Security program is developing technologies to analyze, monitor, and modify the configuration of composed cyber-physical-human systems to identify system vulnerabilities and minimize the attack surface while maintaining functionality and performance. Complex cyber-physical systems, such as ships, airplanes, and critical infrastructure increasingly consist of commodity information technology components. The manual configuration necessary to enable each component to interoperate introduces exploitable cyber vulnerabilities, as do the standard operating procedures that system operators follow. The Configuration Security program will develop capabilities to automate the appropriate configuration of such systems within the operational context. The resulting capability will ensure secure configuration settings and prevent malicious changes to these settings. ***FY 2019 Plans:*** - Develop techniques to automatically generate baseline secure configurations for simple composed cyber-physical-human systems for which informal systems engineering descriptions are available.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Design algorithms to reconfigure a system automatically to a safer, more secure baseline that assures the functionality specified in informal systems engineering descriptions. - Develop an initial capability to detect the malicious modification of configurations from the system-generated baseline for a single operational context. ***FY 2020 Plans:*** - Develop techniques to automatically generate baseline secure configurations for complex composed cyber-physical-human systems, including the translation of human-readable standard operating procedures into machine-understandable formats. - Develop algorithms to reconfigure a system automatically to a safer, quantifiably more secure baseline that assures required functionality and can justify the new configuration parameter selection with generated human-readable explanations. - Mature a capability to both detect and prevent malicious modification of configurations from the system-generated baseline, and to assist system operators in changing between operational contexts. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects expanded algorithm and software development, and initial demonstration of an automated capability to detect and prevent malicious modification of configurations from the system-generated baseline.			
Title: Cyber Assured Systems Engineering (CASE)	24.937	21.400	17.000
Description: The Cyber Assured Systems Engineering (CASE) program is developing the design, analysis and verification tools needed to allow system engineers to design-in cyber resiliency and manage tradeoffs as they do other nonfunctional properties when designing complex embedded computing systems. The current state of practice for cyber resilience utilizes penetration testing after system construction to drive post-design re-engineering. The CASE technical approach formulates cyber resilience as an explicitly engineered property, similar to other holistic properties such as safety, durability, and reliability now standard in systems engineering. CASE will focus on the following technical areas: techniques to derive resilience-related requirements before system design and construction; architectural design and analysis tools to design-in the derived resilience requirements while providing feedback to the human designer to allow for informed tradeoffs between resilience and other system design goals; tools to adapt existing software to support system-level resilience requirements; and inference engines, satisfiability solvers, and provers scalable to complex networked cyber physical systems. If successful, CASE technologies will enable the design of cyber physical systems that robustly execute their intended function despite the efforts of sophisticated cyber adversaries. ***FY 2019 Plans:*** - Create tools to adapt existing software to support system-level resilience requirements. - Develop techniques for translating the output of cyber resilience design tools into concepts relevant to the system designer. - Enhance inference engines, satisfiability solvers, and provers to scale to complex cyber physical systems.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Formulate approaches for representing the intent of software and its abstract constraints separately from its concrete instantiation to enable rapid code synthesis and continual adaptation. - Demonstrate and evaluate design tools and techniques on an initial cyber resilience design challenge problem. ***FY 2020 Plans:*** - Enhance cyber resilience design tools based on the results of initial cyber resilience challenge problem. - Demonstrate and evaluate design tools and techniques on exemplar cyber-physical systems. - Integrate cyber resilience design tools into the engineering workflow of a defense system provider. - Use integrated design tools to re-engineer a portion of a defense platform to improve cyber resiliency. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects ramping down development of techniques and software tools to enable systems engineers to design-in cyber resiliency requirements in a rigorous fashion, and expanded demonstrations on exemplar cyber-physical challenge problems.			
Title: Active Social Engineering Defense (ASED) ***Description:*** The Active Social Engineering Defense (ASED) program is developing technologies to automatically identify, disrupt and investigate social engineering attacks via bot-mediated communications. Social engineering attacks, such as phishing and spear-phishing, typically gain user trust via impersonation to induce behaviors or elicit sensitive information that compromise security of an information system. At present, defending against social engineering attacks falls entirely to users. ASED aims to prevent social engineering attacks by creating counter-social-engineering bots that act on behalf of users to mediate and aggregate communications, and auto-identify attackers. If successful, ASED will greatly reduce the effectiveness of adversary social engineering attacks and improve the security of DoD information systems. ***FY 2019 Plans:*** - Use big data techniques to characterize internet communications and rapidly detect social engineering attacks. - Develop machine-learning-based intelligent bots that can actively engage with attackers. - Develop initial capability for semi-automated attribution of social engineering attacks. - Assess performance of bot-based counter-social-engineering techniques on synthetic attack data. ***FY 2020 Plans:*** - Create capability to autonomously detect social engineering attacks across multiple communication platforms. - Demonstrate semi-automated attribution of social engineering attacks. - Develop initial capability for multiple, coordinated counter-social-engineering bots to conduct fully-autonomous investigations of social engineering attacks.	10.000	15.524	13.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Perform evaluations to determine effectiveness and efficiency of social engineering detection and investigation techniques. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease is the result of development work ramping down as program focus shifts to evaluating the performance of the social engineering detection and investigation technologies.			
Title: Leveraging the Analog Domain for Security (LADS) ***Description:*** The Leveraging the Analog Domain for Security (LADS) program is developing 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 hidden. ***FY 2019 Plans:*** - Design antenna arrays and develop signal pre-processing techniques to improve signal-to-noise properties and enable higher-fidelity device monitoring from longer distances against both Internet of Things (IoT) devices and more complex devices such as thin-clients, feature phones, smart phones, laptops, and servers. - Characterize and model the signals from complex devices operating in secure/correct and compromised/faulty states. - Refine side channel models and use them to guide the development of software-based signal boosting techniques. ***FY 2020 Plans:*** - Explore distance/accuracy tradeoffs for discriminating between known/unknown code running on a device, and develop techniques to improve performance by integrating multiple analog side channels. - Extend and apply signal analysis techniques to highly complex devices, including those with field programmable gate arrays. - Support potential transition partners in test and evaluation. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease is the result of development work ramping down and the focus shifting to optimization of techniques for use in operational environments and technology transition.	16.700	15.300	12.000
Title: Brandeis ***Description:*** 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. Brandeis will resolve the tension between maintaining privacy and being able to tap into the huge value of data. In the civilian sphere, there is a recognized need for technologies that enable the controlled sharing of information between commercial entities and U.S. government agencies.	17.000	18.870	6.520

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Similarly, the U.S. military is increasingly involved in operations that require highly selective sharing of data with a heterogeneous mix of allies, coalition partners, and other stakeholders. Brandeis technologies are being designed to work with the virtualization, cloud computing, and software-defined networking technologies now widely used in both civilian and military environments. ***FY 2019 Plans:*** - Scale up secure multiparty computation, secure database queries, differential privacy, and remote attestation techniques to U.S. government and DoD data repositories. - Demonstrate privacy-preserving communication and collaboration techniques in real-world exercises on enterprise networks. - Incorporate privacy-preserving technologies in flexible toolkits and transition to U.S. government and DoD partners. ***FY 2020 Plans:*** - Extend techniques to address challenging use cases such as collaborative surveillance allocation and privacy-preserving combination of sensitive data sets. - Participate in exercises that demonstrate privacy protection in data communication and collaboration with allies and non-governmental organizations. - Transition secure multi-party computation libraries and privacy preserving technologies to open source repositories and to U.S. government and DoD partners. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease is the result of development work ramping down, continued efforts to demonstrate technologies on U.S. government and DoD use cases, and technology transition.			
Title: Extreme Distributed Denial of Service Defense (XD3) ***Description:*** The Extreme Distributed Denial of Service Defense (XD3) program is developing new computer networking architectures that deter, detect, and overcome distributed denial of service (DDoS) attacks. DDoS attacks include both high-volume flooding attacks and more subtle low-volume attacks that evade traditional intrusion detection systems while exhausting server processing and memory. These attacks will accelerate as the Internet of Things (IoT) incorporates new classes of devices that in many cases will be deployed with inadequate security controls: attackers will assimilate poorly defended IoT devices into 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 2019 Plans:*** - Incorporate feedback received during exercises to enhance maneuver, deception, dispersion, and on-host adaptation techniques.	20.386	12.500	5.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Test and verify the intended operation of the prototype defensive architectures by subjecting techniques to simulated DDoS attacks. - Pursue transition to DoD network service providers and commercial network operators through demonstrations in operational network environments. ***FY 2020 Plans:*** - Harden technologies and complete transition to DoD network service providers and commercial network operators. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease is the result of XD3 development work concluding and the focus shifting to hardening technologies for transition partners.			
Title: Memory Optimization (MemOp) ***Description:*** The Memory Optimization (MemOp) program, building upon technologies developed in the Dispersed Computing program, will develop technology to optimize memory transactions in large scale computing systems. The demand for computing services is growing within both the U.S. government and commercial industry. In response, new technical approaches are being developed to provide massive computation efficiently and cost effectively. In particular, distributed data centers with high-speed interconnects and customizable hardware including graphics processing units (GPU) and field programmable gate arrays (FPGAs) are being used by service providers to achieve greater efficiency and improved processing performance. MemOp will explore new memory architectures that more fully leverage emerging customizable hardware to deliver computing services reliably and at reduced cost. The more promising MemOp memory architectures will be implemented and evaluated in hardware and software. The technologies developed in MemOp will provide enhanced efficiency and improved performance for large scale computing systems. ***FY 2019 Plans:*** - Formulate approaches, algorithms, and architectures for optimizing memory transactions in large scale computing systems. - Identify commercial off-the-shelf (COTS) and governments off-the-shelf (GOTS) hardware and software systems appropriate for modifications and testing of techniques for optimizing memory transactions. ***FY 2020 Plans:*** - Reduce the complexity of algorithms that map software tasks to processing units to achieve scalability to large scale memory systems. - Develop methods to interface to memory and develop accelerated processing pipelines for optimizations of interest. - Establish a test-bed to evaluate memory transaction improvements in systems incorporating GPUs and FPGAs.	-	8.955	22.200

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Implement algorithms and architectures for improving memory transaction performance in hardware and software and evaluate on MemOp test-bed. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects expanded efforts to develop memory interface methods, accelerated processing pipelines, and an evaluation test-bed.			
Title: Resilient Anonymous Communication for Everyone (RACE) ***Description:*** The Resilient Anonymous Communication for Everyone (RACE) program, building on technologies pioneered within the SafeWare program (PE 0601101E, Project CYS-01), will develop cryptographic and communication obfuscation technologies to enable anonymous, attack-resilient, mobile communications within a network environment. RACE will develop a mobile phone application and distributed systems that provide a secure message-passing service by combining advances in distributed system tasking with communication protocol encapsulation methods. The RACE system will maintain confidentiality, integrity, and availability of messaging while preventing large-scale compromise of the system. RACE security will be based on rigorous security arguments or in statistical arguments based on realistic simulations, and not on ad hoc security claims. ***FY 2019 Plans:*** - Formulate concepts for combining distributed system tasking, secure multiparty computation, and communication protocol encapsulation technologies in a message-passing system that cannot be compromised by a cyber adversary in a network environment. ***FY 2020 Plans:*** - Develop and implement techniques to prevent a cyber adversary from discovering the presence of and compromising the secure message-passing system by obfuscating communication protocols and encrypting data on the nodes at all times, even during computation. - Build an initial secure message-passing system that can defeat the efforts of a cyber adversary with limited ability to observe the network. - Initiate development of a test-bed on which to evaluate implementations of the obfuscation and cryptographic technologies and the integrated secure message-passing system against a simulated cyber adversary. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects expanded development of obfuscation and encryption technologies, initial implementation of a secure message-passing system, and construction of a test-bed on which to evaluate the system against a simulated cyber adversary.	-	7.000	17.300
Title: Cora	-	7.400	12.430

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Description: The Cora program, building on technologies pioneered in the Memex program (PE 0602702E, Project TT-13), will develop technologies to enable machines to read heterogeneous text-based data sources, extract key entities and activities, and characterize cyber threats. Large volumes of text-based data contain scattered clues about the activities of cyber threats. Automated machine reading and analysis capabilities are required due to the extreme rates at which this text-based data is generated. In addition, the connections between extracted entities and their activities can be very subtle and, because they are buried in noise, difficult to detect and correlate. The Cora technologies will benefit cyber analysts by providing them with pre-processed cyber leads that might otherwise not be available. ***FY 2019 Plans:*** - Develop machine reading and entity extraction approaches for cyber analysis of text-based data. - Formulate techniques for correlating the activities of extracted cyber entities across large text corpora. - Initiate development of a large-scale platform for evaluating cyber analytical technologies. ***FY 2020 Plans:*** - Implement machine reading, cyber entity extraction, and activity correlation techniques in an integrated software system. - Evaluate cyber analytical technologies on large-scale data and implement algorithmic improvements to address scalability and performance. - Provide initial software capabilities to potential transition partners for performance assessments in operational environments. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects expanded efforts to develop an integrated cyber analytical system, expanded evaluation on large-scale data, and technology transition.			
Title: Searchlight* ***Description:*** *Formerly Protecting C3 Networks (PC3N) The Searchlight program will develop technologies to ensure quality-of-service (QoS) guarantees are met for distributed applications operating across the Internet. The increasing use of Internet-based distributed applications creates risks as surges in network use can result in resource shortfalls. Searchlight will develop novel approaches for allocating inherently limited network resources to optimize the performance of distributed applications. Searchlight techniques and systems will enable organizations to adapt the QoS for their low-priority traffic to result in improved QoS for their high-priority traffic without affecting traffic from other Internet users. ***FY 2019 Plans:***	-	3.800	6.900

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Formulate big data and machine learning based schemes for adapting the QoS of low-priority distributed applications to improve the QoS of high-priority distributed applications. ***FY 2020 Plans:*** - Define a unified framework for network QoS requirements for diverse distributed applications. - Define metrics for the integrated QoS of a heterogeneous suite of distributed applications having differing and dynamic priorities. - Implement QoS adaptation schemes on programmable network elements such as software-defined routers and switches. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects expanded development work to implement QoS adaptation schemes on programmable network elements.			
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. 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 exhibit differences in behavior under cyber attack, so that CFAR-enabled computing systems will quickly detect deviations in processing elements at attack onset and rapidly reboot to restore affected services. CFAR technologies are being developed in coordination with operational users. ***FY 2019 Plans:*** - Demonstrate an integrated CFAR system that protects against a wide range of threats in an operational environment. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.	17.030	6.000	-
Title: Edge-Directed Cyber Technologies for Reliable Mission Communication (EdgeCT) ***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. EdgeCT algorithms and software prototypes are implemented exclusively at the network edge, specifically on end hosts and/or on proxy servers fronting groups of such end hosts within a user enclave. EdgeCT systems 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 enables highly reliable networked communication for the military in the face of a wide variety of common network failure modes as well as cyber attacks	9.280	3.000	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
against network infrastructure. EdgeCT technologies are developed in coordination with operational commands and commercial service providers. ***FY 2019 Plans:*** - Harden technologies and complete transition to DoD's commercial network operators. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Title: System Security Integrated Through Hardware and firmware (SSITH) ***Description:*** The System Security Integrated Through Hardware and firmware (SSITH) program seeks to secure DoD and commercial electronic systems against cybersecurity threats by developing novel hardware/firmware security architectures and hardware design methodologies. Current responses to cybersecurity attacks typically consist of developing and deploying software patches to address specific vulnerabilities in a software firewall without addressing potential vulnerabilities in the underlying hardware architecture. To address this challenge, SSITH will drive new research in electronics hardware security and exploit current research in areas such as cryptographic-based computing and hardware verification. Implementation of these advanced ideas has been enabled by the extremely capable semiconductor technology driven by Moore's Law. The program will also investigate flexible hardware architectures that adapt to and limit the impact of new cybersecurity attacks. Finally, SSITH will seek to mitigate the potential negative impact of new security protection architectures on system performance and power usage. Once developed, SSITH capabilities will be applicable to both commercial and military electronic systems. The SSITH program moves to Project ELT-02, Beyond Scaling Technology, in FY 2019.	18.420	-	-
Title: Supply Chain Hardware Integrity for Electronics Defense (SHIELD) ***Description:*** The Supply Chain Hardware Integrity for Electronics Defense (SHIELD) program aimed to develop a technology capable of confirming the authenticity of electronic parts at any time and place. Authenticating parts or detecting counterfeit components by current means has proven expensive, time-consuming, and of limited effectiveness. An alternative solution, maintaining complete control of the global supply chain using administrative controls, can also incur substantial costs. SHIELD instead sought to incorporate a small, inexpensive silicon chip ("dielet") into the packaging of genuine components. The dielet provided unique and encrypted component identification, enabling authentication from very close proximity. Since counterfeit electronic components pose a threat to the integrity and reliability of both commercial and DoD systems, SHIELD fulfilled a large, pressing, and evolving need for anti-counterfeit technologies.	5.000	-	-
Title: Plan X	4.000	-	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Description: The Plan X program developed technologies 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 created new graphical interfaces that enable intuitive visualization of events on hosts and networks to aid in the planning and execution of cyber warfare, and operationally meaningful measures to assess the effectiveness of cyber warfare missions.			
Accomplishments/Planned Programs Subtotals	262.375	255.919	258.850

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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COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
IT-04: *ARTIFICIAL INTELLIGENCE AND HUMAN-MACHINE SYMBIOSIS*	-	69.197	96.864	161.168	-	161.168	166.862	170.253	181.921	188.921	-	-

A. Mission Description and Budget Item Justification

The Artificial Intelligence and Human-Machine Symbiosis project develops technologies to enable machines to function not only as tools that facilitate human action but as trusted partners to human operators. Of particular interest are systems that can understand human speech and extract information contained in diverse media; answer questions, reach conclusions, and propose explanations; and learn, reason, and apply knowledge gained through experience to respond intelligently to new and unforeseen events. Enabling computing systems with such human-like intelligence is now of critical importance because the tempo of military operations in emerging domains exceeds that at which unaided humans can orient, understand, and act. The technologies developed in the Artificial Intelligence and Human-Machine Symbiosis project 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 and semi-autonomous agents to perform critical missions in contested physical and virtual environments safely and reliably.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Explainable Artificial Intelligence (XAI)	17.446	18.830	26.050
Description: The Explainable Artificial Intelligence (XAI) program is developing a new generation of machine learning techniques that are able to produce a rationale to explain the conclusions they reach. If current trends continue, future U.S. military autonomous systems will need to perform increasingly complex and sensitive missions, and AI will be critical to such systems. However, in order for developers, users, and senior leaders to feel confident enough to deploy and use AI-enabled systems, these systems must be able to explain their rationale, and their recommendations, decisions, and actions must be delivered in a way that military users can understand and trust. Today, most machine learning systems provide no explanations, or provide explanations that are too detailed, at the wrong level of abstraction, or not meaningful to a human user. XAI will develop the tools necessary to build explainable AI systems, in particular (1) new machine learning techniques that produce human-interpretable models and (2) user interfaces that generate explanations from those models meaningful to end-users. XAI implementations will be developed and demonstrated in next-generation autonomous, data analytics, and decision-support systems.			
FY 2019 Plans: - Evaluate the performance of the initial prototype systems against developer-selected test problems in autonomy and data analytics. - Formulate improved explainable machine learning methods and modified deep learning techniques, integrate these into prototypes, and refine and test.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-04 / *ARTIFICIAL INTELLIGENCE AND HUMAN-MACHINE SYMBIOSIS*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Define a set of test problems in data analytics and autonomous systems for understanding explanation effectiveness of the systems. - Refine a computational model of the theory of explanation in artificial intelligence, and demonstrate the ability of the computational model to predict the performance of explanations generated by the systems. ***FY 2020 Plans:*** - Evaluate the performance and the explanation effectiveness against government-selected test problems in autonomy and data analytics. - Optimize explainable machine learning techniques and user interfaces for integration into prototype systems. - Expand the set of test problems in data analytics and autonomous systems for evaluating explanation effectiveness of the systems. - Refine the computational model of explanation, and show increased ability to predict the performance of explanations generated by the systems. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects continued development of explainable machine learning techniques, accelerated integration of techniques in machine learning systems, and expanded testing on problems in data analytics and autonomous systems.			
Title: Assured Autonomy	15.700	17.520	25.550
Description: The Assured Autonomy program is developing rigorous design and analysis technologies for continual assurance of learning-enabled autonomous systems to guarantee safety properties in uncertain environments. Currently, the state of the art for test, evaluation, verification and validation is only applicable to non-learning systems operating in well-characterized environments. As a result, autonomous systems enabled by machine learning (e.g., deep neural nets for perception, reinforcement learning for control policies, and online model learning) lack rigorous safety assurance. Assured Autonomy is developing new techniques for modeling and system design, formal verification, simulation-based testing, machine learning, and safety-assured learning to provide continual assurance of learning-enabled autonomous systems. The technologies being developed in Assured Autonomy will enable the DoD to more rapidly and efficiently deploy learning-enabled autonomous systems that can be trusted to operate safely in uncertain environments. ***FY 2019 Plans:*** - Develop techniques and tools that construct formal semantics of assurance cases, provide dynamic interpretation of assurance cases, and modularize and automatically generate assurance cases from system design descriptions. - Develop algorithms that integrate and enforce safety constraints in learning-enabled systems.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-04 / *ARTIFICIAL INTELLIGENCE AND HUMAN-MACHINE SYMBIOSIS*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Produce assurance challenge problems for different learning-enabled autonomous systems, and evaluate the effectiveness of safety-aware learning and safety constraint enforcement techniques. ***FY 2020 Plans:*** - Develop scalable methods addressing formal verification of safety properties of learning-enabled autonomous systems and scalable algorithms for dynamic evaluation of assurance cases. - Construct monitors to detect data-distribution shifts as the operating environment diverges from the training environment. - Assess the reliability and sensitivity of techniques to modeling assumptions for different learning-enabled autonomous systems. - Apply technologies to assurance challenge problems for several learning-enabled autonomous platforms of interest to the DoD. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase is the result of development work accelerating and technologies being tested on several learning-enabled autonomous platforms.			
Title: Active Interpretation of Disparate Alternatives (AIDA) ***Description:*** The Active Interpretation of Disparate Alternatives (AIDA) program is developing a multi-hypothesis semantic engine that generates alternative interpretations of events, situations, and trends from a variety of unstructured sources for use in environments where there are noisy, conflicting, and potentially deceptive data. At present, information from each medium is often analyzed independently, without the context provided by information from other media, resulting in only one interpretation with alternatives being eliminated due to lack of evidence even in the absence of contradictory evidence. AIDA seeks to develop and demonstrate technology to automatically map information derived from multiple sources into a common semantic representation, aggregate information, resolve ambiguities, discover conflicting information, and generate and explore multiple interpretations of events, situations, and trends. If successful, AIDA will provide decision makers a capability to understand alternative explanations for available information and to make contingency plans accordingly. ***FY 2019 Plans:*** - Develop scalable automated techniques to integrate diverse information from multiple high-volume sources into the common semantic representation. - Develop techniques to extend and evolve existing ontologies using information from diverse sources. - Develop techniques to estimate the confidence of the generated interpretations, and formulate approaches for evaluating the accuracy of confidence estimates. - Evaluate techniques to identify semantically consistent adversarial misinformation on synthetic data. ***FY 2020 Plans:*** - Enhance multimedia analytics through use of feedback from generated hypotheses. - Develop techniques to limit the over-generation of hypotheses by automatically discarding irrelevant or duplicated hypotheses.	16.850	17.780	25.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-04 / *ARTIFICIAL INTELLIGENCE AND HUMAN-MACHINE SYMBIOSIS*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Develop an intuitive interface to allow users to modify the extracted semantic elements and the generated hypotheses at any stage of the analysis. - Collaborate with transition partners to assess the validity and completeness of generated hypotheses using real-world data. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects continued development of techniques for generating multiple alternative interpretations from multimedia data and expanded adversarial evaluations of techniques on synthetic and real-world data.			
Title: Low Resource Languages for Emergent Incidents (LORELEI) ***Description:*** The Low Resource Languages for Emergent Incidents (LORELEI) program is developing technology to rapidly field machine translation and other language processing capabilities for low-resource foreign languages. The U.S. 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. Processing foreign language materials requires 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 takes 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 2019 Plans:*** - Develop techniques to establish situational awareness from text and speech of low-resource languages. - Extend development of techniques to determine strength of opinions and beliefs to understand urgency and status of emerging situations. - Evaluate performance on additional languages, and measure progress on the languages evaluated in the previous year. ***FY 2020 Plans:*** - Implement final improvements and demonstrate capabilities on languages of interest to potential transition sponsors. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease is the result of development work ramping down and focus shifting to technology refinement.	19.201	9.130	4.000
Title: Human-Machine Symbiosis (HMS) ***Description:*** The Human-Machine Symbiosis (HMS) program will conduct applied research to enable machines to collaborate with humans as colleagues, partners, and teammates. The world is moving faster than humans can assimilate, understand, and act. At present, we design machines to handle well-defined, high-volume or high-speed tasks, freeing humans to focus	-	8.604	16.883

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-04 / *ARTIFICIAL INTELLIGENCE AND HUMAN-MACHINE SYMBIOSIS*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
on complexity. If successful, HMS technologies will enable machines to do more than execute pre-programmed instructions. Rather, HMS-enabled machines will understand speech; extract information contained in diverse media; learn, reason and apply knowledge gained through experience; identify and work to fill knowledge gaps; extrapolate causal phenomena to anticipate predictable outcomes; and respond intelligently to new and unforeseen events. A companion basic research effort is funded in PE 0601101E, Project CCS-02. ***FY 2019 Plans:*** - Create human-aligned agent technologies that learn to support individual human operators in the performance of planning tasks. - Devise social Artificial Intelligence (AI) approaches for creating high-performing human-machine teams of individuals and semi-autonomous systems with complementary characteristics/capabilities. - Identify extensions to algorithmic game theory based AI techniques needed for complex military decision problems. - Develop methods for extracting generalized and compressed knowledge representations from data and information to enable more adaptable AI and machine learning approaches. ***FY 2020 Plans:*** - Formulate goal reasoning techniques to serve as the basis for curious machines that identify and fill knowledge gaps. - Design computational agents capable of advising and guiding humans in the performance of real-world tasks. - Develop and demonstrate social AI-based techniques for evaluating and selecting human-machine teams that perform at a higher level than teams constituted using only individual performance assessment techniques. - Incorporate generalized and compressed representations of knowledge in AI and machine learning systems that improve performance on tasks as they gain experience and receive feedback from a human operator. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects expanded work to integrate human-machine symbiosis technologies into a system for assessment.			
Title: Automated Knowledge Acquisition (AKA)	-	-	24.100
Description: The Automated Knowledge Acquisition (AKA) program will develop technologies to automate the integration of diverse sources of data and information into a unified whole. A number of technologies now exist to extract, transform, and load diverse source data into a structured knowledge base. However, each time a new source of data is encountered, a human engineer is required to map that source's metadata and schema to the metadata and schema of the target knowledge base. Performing this mapping is difficult even when design documentation for the source is available, and so it represents a significant barrier to data interoperability and knowledge acquisition. AKA will leverage advances in semantic technology and machine learning to enable machines to perform the entire data integration function without human intervention. AKA technology will automatically learn the semantics of a new data source, characterize source content, align source schema to the target, transform and load values, and reconcile inconsistencies by learning from previously integrated sources. AKA technologies will			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-04 / *ARTIFICIAL INTELLIGENCE AND HUMAN-MACHINE SYMBIOSIS*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
automatically create and maintain, in real-time, broad knowledge of local and regional military, political, economic, social, and cultural information for warfighters in theater. ***FY 2020 Plans:*** - Apply natural language understanding and machine learning techniques to the problem of automating schema alignment. - Develop approaches for reconciling inconsistencies and assuring integrity of a unified knowledge base created from diverse sources. - Propose an upper ontology to accommodate domain-specific ontologies of interest to military users engaged in human domain operations for which local and regional military, political, economic, social, and cultural factors can be important. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.			
Title: Accelerating Artificial Intelligence (AAI) ***Description:*** The Accelerating Artificial Intelligence (AAI) program seeks to go beyond commercially-driven advances in AI and address important national security challenge applications. In particular, this program is focused on improving DoD processes that, because of the need for excessive human involvement, create bottlenecks in DoD's ability to rapidly adapt and deploy new technologies and capabilities. If successful, research efforts under this program will significantly reduce the time and cost associated with many important developmental, approval and certification processes. One technical challenge to be addressed in this program is the need to assess current processes and identify tasks or sub-tasks amenable to minimal human intervention. Other challenges include the need to develop social context aware AI systems and to ensure robustness of AI systems. Approaches to addressing these challenges will leverage recent advances at the frontiers of AI research in transfer learning, causal reasoning and associated models. AAI application areas include the following: (1) machine-enabled techniques to reduce human engagement in determining trustworthiness and intent; (2) automated approaches for accreditation of military software systems; and (3) technologies to restore movement and sensation to central nervous system impaired patients. ***FY 2020 Plans:*** - Evaluate current approaches for assessing trustworthiness and identify tasks or sub-tasks amenable to minimal human intervention. - Apply AI to identify the most effective methods for assessing trustworthiness and intent as a function of social context. - Identify data sources for development and training of AI systems for machine assisted human interviews and vetting processes. - Develop, demonstrate, and evaluate pilot application using algorithmic game theory based AI techniques for complex military decision problems. ***FY 2019 to FY 2020 Increase/Decrease Statement:***	-	-	24.100

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-04 / *ARTIFICIAL INTELLIGENCE AND HUMAN-MACHINE SYMBIOSIS*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The FY 2020 increase reflects program initiation.			
Title: Knowledge-directed AI Reasoning Over Schemas (KAIROS)	-	-	15.485
Description: The Knowledge-directed Artificial Intelligence (AI) Reasoning over Schemas (KAIROS) program will develop AI and machine learning technologies to aid a human operator in understanding complex event sequences. For the purposes of KAIROS, an event is an occurrence that results in an observable and recognizable change in either the physical world or human society. Events of particular interest to KAIROS are those that create changes that have significant impact on national or homeland security. Many important events are not simple occurrences but complex phenomena that are composed of numerous subsidiary event elements, some of which happen simultaneously while others are sequential and dependent on each other. Humans make sense of event sequences by organizing them into narrative structures that may occur or re-occur frequently. These structures are abstracted into schemas - organized units of knowledge that represent patterns - for the purpose of cognition. The KAIROS program will develop automated systems that use existing schemas and, when needed, create new schemas to bring structure to complex event sequences and present these structured representations to operators. Given multi-media inputs, operators will use KAIROS technologies to identify subsidiary event elements, determine their temporal order, recognize complex event sequences, and link disparate events. KAIROS technologies will enable analysts and warfighters to understand unfolding events rapidly and accurately. ***FY 2020 Plans:*** - Develop and apply AI and statistical pattern recognition techniques for machine learning of new temporal schemas from intelligence data. - Develop temporal schema to recognize patterns in complex event sequences. - Develop techniques for quantifying the degree to which a temporal schema models a complex sequence of event elements and for quantifying the degree of confidence in reconstructions. - Explore approaches for using partial matches to temporal schema to interpolate or predict missing or future event elements, respectively. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.			
Accomplishments/Planned Programs Subtotals	69.197	71.864	161.168

	FY 2018	FY 2019
Congressional Add: DARPA Foundational and Applied Artificial Intelligence	-	25.000
FY 2019 Plans: - Define temporal schemas for a broad range of event sequences including in particular events of potential interest to military decision makers.		

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-04 / *ARTIFICIAL INTELLIGENCE AND HUMAN-MACHINE SYMBIOSIS*

	FY 2018	FY 2019
- Formulate top-down approaches for associating events under analysis with existing temporal schemas. - Explore approaches that enable adaptation of natural language processing and computer vision technologies to chemistry data.		
Congressional Adds Subtotals	-	25.000

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 2020 Defense Advanced Research Projects Agency	Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	15.078	33.640	34.588	-	34.588	29.836	39.536	38.536	38.536	-	-
BW-01: *BIOLOGICAL WARFARE DEFENSE*	-	15.078	33.640	34.588	-	34.588	29.836	39.536	38.536	38.536	-	-

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 included: countermeasures to stop the pathophysiologic processes that occur as a consequence of an attack; collection of environmental trace constituents to support chemical mapping, tactical and strategic biological, chemical, and radiological sensors; and integrated defense systems. This project 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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	13.014	38.640	44.346	-	44.346
Current President's Budget	15.078	33.640	34.588	-	34.588
Total Adjustments	2.064	-5.000	-9.758	-	-9.758
• 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	2.065	0.000			
• SBIR/STTR Transfer	-0.001	0.000			
• TotalOtherAdjustments	-	-	-9.758	-	-9.758

Change Summary Explanation

FY 2018: Increase reflects reprogrammings offset by SBIR/STTR transfer.
FY 2019: Decrease reflects Congressional reduction.
FY 2020: Decrease reflects Defense Against Mass Terror Threats program technology down-select to develop the initial chemical and biological sensor set.

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Defense Against Mass Terror Threats	15.078	33.640	34.588

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
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 Weapon of Mass Terror (WMT) attack. Challenges in reducing U.S. vulnerability to these attacks include developing new sensors and systems that afford early warning and opportunities to interdict these threats before they can be employed in urban areas and other population centers. A major goal of this program is to develop new sensors and sensing networks that can economically and reliably provide these wide-area monitoring capabilities for WMT threat signatures. ***FY 2019 Plans:*** - Begin process to make an open source, continuous, wide-area sensing platform. - Begin research and development of advanced chemical and biological sensors for wide-area sensing. - Initiate advanced network algorithms for new sensing modalities and data fusion. - Begin to develop general interfaces to supply advanced WMT monitoring capabilities to existing, operational, and situational awareness systems. - Demonstrate feasibility of continuous sensing network scalability to city-sized areas through simulation for multiple classes of WMT threats, including chemical and biological. - Commence development of advanced adversary prediction models to improve overall system interdiction capabilities. ***FY 2020 Plans:*** - Initiate development of a continuous, wide-area sensing platform for the full spectrum of WMT threats through integration of prior and on-going research and development in advanced physical sensors, automated intelligence and network algorithms, open source IT platforms, and advanced adversary models. - Test, down-select, and further develop initial chemical and biological sensor set based on sensor specificity, sensitivity, and time to detection performance to enable scalable wide-area sensing. - Continue development of an open source, continuous, wide-area sensing IT platform capable of simultaneous ingress and fused analysis of thousands of real-time, multi-modal physical sensor and information feeds. - Continue development of algorithms capable of multi-modal sensor and information fusion, weighted by potential adversary behaviors learned from scaled social science models, for threat detection that maximizes sensitivity while minimizing false alarms. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects minor program repricing.			
Accomplishments/Planned Programs Subtotals	15.078	33.640	34.588

D. Other Program Funding Summary ($ in Millions)

N/A

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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*

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-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	292.957	309.466	337.602	-	337.602	283.854	256.281	280.592	289.652	-	-
TT-03: *NAVAL WARFARE TECHNOLOGY*	-	32.535	44.771	42.859	-	42.859	10.534	11.059	29.059	34.059	-	-
TT-04: *ADVANCED LAND SYSTEMS TECHNOLOGY*	-	80.428	109.286	138.040	-	138.040	118.783	83.948	76.891	75.951	-	-
TT-07: *AERONAUTICS TECHNOLOGY*	-	60.151	50.799	53.119	-	53.119	47.328	59.119	47.528	47.528	-	-
TT-13: *INFORMATION ANALYTICS TECHNOLOGY*	-	119.843	104.610	103.584	-	103.584	107.209	102.155	127.114	132.114	-	-

A. Mission Description and Budget Item Justification

The Tactical Technology 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, Aeronautics Technology and Information Analytics 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 develop methods that fundamentally change the calculus of battle including consideration of a mix of assets, potentially disposable or with limited lifespans, with increased levels of autonomy are included.

The Aeronautics Technology project addresses 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 Information Analytics Technology project develops technology for analyzing data and 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

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*

of diverse, incomplete, and uncertain data in tactically-relevant timeframes. Benefits sought include deeper understanding of the evolving operational environment tailored to the needs of commanders at every echelon; an enhanced capability to plan, monitor, and control diverse military operations ranging from stability operations to combat; and improvements to the efficiency of core military functions such as national and homeland security, warfighter health and readiness, and defense support of law enforcement and civil authorities. Promising technologies are evaluated in the laboratory and demonstrated in the field to facilitate transition.

B. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	343.776	335.466	344.387	-	344.387
Current President's Budget	292.957	309.466	337.602	-	337.602
Total Adjustments	-50.819	-26.000	-6.785	-	-6.785
• Congressional General Reductions	-32.966	-26.000			
• 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	-5.689	0.000			
• SBIR/STTR Transfer	-12.164	0.000			
• TotalOtherAdjustments	-	-	-6.785	-	-6.785

Change Summary Explanation

FY 2018: Decrease reflects Congressional reduction, SBIR/STTR transfer and reprogrammings.
FY 2019: Decrease reflects Congressional reduction.
FY 2020: Decrease reflects minor program repricing.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
TT-03: *NAVAL WARFARE TECHNOLOGY*	-	32.535	44.771	42.859	-	42.859	10.534	11.059	29.059	34.059	-	-

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 to include the entire sea column 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, methods and techniques for servicing assets throughout the sea column, and high bandwidth communications. This project will also examine methods and architectures for distributing maritime operations to enable a more agile, survivable, and cost-effective fleet.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Multi-Azimuth Defense Fast Intercept Round Engagement System (MAD-FIRES)	32.535	32.771	29.859
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 advances 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 2019 Plans: - Begin detailed design of system prototype that includes projectile, gun system, and fire control system. - Update projectile design based on previous year flight test results. - Validate sensor modeling and simulation through realistic environment testing. - Verify projectile compatibility with high speed gun feed system. - Verify fire control system ability to acquire and track surrogate threats.			
FY 2020 Plans: - Verify fire control system ability to guide rounds to target.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Perform end-to-end demonstration of gun launched guided flight. - Begin detailed planning for end-to-end system demonstration against surrogate targets. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects completion of design and fabrication activities.			
Title: Angler* ***Description:*** *Formerly Lobster The undersea domain has significant importance to national security and military operations. Yet it is a challenging domain in which to operate due to extreme water pressures, restricted communications, ever changing bottom environments, marine fouling and corrosion. The Angler program seeks to improve U.S. operations in this domain by enabling underwater robotic systems significantly ahead of the state of the art. These robotic systems would be able to search and manipulate objects autonomously, even in dark, turbulent, and semi-opaque sea conditions without the need for human control and without reliance on the Global Positioning System (GPS). Key Angler technical challenges include sensing techniques that provide high-resolution navigation without GPS, perception and manipulation strategies for objects with unknown parameters, long duration autonomy approaches to support mission execution, and autonomy approaches that do not rely on human intervention. In FY 2020, this program is also funded in PE 0603766E, Project NET-02. The anticipated transition is to the Navy. ***FY 2019 Plans:*** - Conduct exploratory trade studies to establish feasibility of technical approaches. - Initiate systems engineering and begin design of prototype architecture for autonomous, undersea manipulation operations. ***FY 2020 Plans:*** - Complete Conceptual Design Review (CDR). - Conduct Preliminary Design Review (PDR). - Test robot subsystems in laboratory or simulation environments. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects initiation of PDR and testing activities.	-	12.000	13.000
Accomplishments/Planned Programs Subtotals	32.535	44.771	42.859

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-03 / *NAVAL WARFARE TECHNOLOGY*

C. Other Program Funding Summary ($ in Millions)

Line Item	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
• ACTUV: *Office of Naval Research MOA*	3.917	0.000	0.000	-	0.000	0.000	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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
TT-04: *ADVANCED LAND SYSTEMS TECHNOLOGY*	-	80.428	109.286	138.040	-	138.040	118.783	83.948	76.891	75.951	-	-

A. Mission Description and Budget Item Justification

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. Programs seek to break the relative symmetry of land combat to give U.S. forces a decided advantage in the current and future ground battlefield. The emphasis is on developing affordable technologies that reduce reliance on consolidated forward-operating bases and required lines of communication, and provide small units and individual warfighters with hyper-mobility and hyper-lethality. This project will develop methods and technologies to expand the maneuver trade space to include the vertical dimension, including subterranean environments, and will leverage advances in artificial intelligence to enable integrated manned-unmanned operations and decrease warfighter exposure through the use of autonomous agents.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Squad X	27.928	28.286	26.040
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 an advanced, dismounted small unit.			
FY 2019 Plans: - Complete initial technology development efforts focusing on human machine interfaces, the squad common operating picture in three dimensions, and the synchronization of kinetic and non-kinetic engagement capabilities. - Complete initial squad-system development efforts focusing on an automatic, augmenting system to increase squad performance and the integration of previously developed technology to enhance dismounted operations. - Conduct system-level experimentation and evaluation in relevant conditions with operational units with increased number of humans and unmanned systems in the squad. - Demonstrate mission planning, rehearsal, and playback capabilities using the squad-leader-in-the-loop (SLIL) 3D simulation environment.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Initiate expanded squad-system development efforts with focus on increased squad performance against threat capabilities analogous to near-peer/peer states. - Design and develop integrated systems, to include addition of new sensors, unmanned systems, engagement capabilities, and improved decision algorithms. ***FY 2020 Plans:*** - Continue expanded squad system development efforts focusing on enhanced situational awareness and engagement capabilities. - Continue to develop and optimize the squad common world model and intelligent decision engine. - Continue to leverage the SLIL environment to plan and rehearse missions with increased squad system/subsystem and threat capabilities. - Optimize autonomous cross-cuing of squad assets and sensor nodes, and integrated kinetic and non-kinetic engagement capabilities. - Integrate multiple unmanned nodes into the squad system, with enhanced mobility and/or payload capabilities. - Conduct increasingly complex system-level experimentation and evaluation with operational units, to include: increased number of humans and unmanned systems in the squad and new squad technologies/capabilities. - Experiment with system performance in multiple locations, terrains and environments. - Experiment with system performance against multiple, technology-enabled adversaries with capabilities analogous to near-peer/peer states. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY2020 decrease reflects completion of integrated system development and transition to testing and experimentation of systems.			
Title: Mobile Force Protection (MFP)	30.500	37.000	19.000
Description: The goal of the Mobile Force Protection (MFP) program is to develop and demonstrate an integrated system capable of defeating a raid of self-guided small unmanned aircraft (sUAS) attacking a high value convoy on the move. By focusing on protecting mobile assets, the program will emphasize low footprint solutions, in terms of size, weight, power (SWaP), and manning, which will benefit other counter UAS missions and result in more affordable systems. Defending in a variety of operating environments against these sUAS threats and associated concept of operations requires several breakthroughs in affordable technology to sense, decide and act on a compressed timeline while mitigating collateral damage. The program seeks to develop solutions applicable to the defense of mobile ground and naval forces that can also potentially defeat more conventional threats. The solution will be scalable and modular such that it can be deployed in multiple defense applications and does not become obsolete with evolving threat capability.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
FY 2019 Plans: - Update affordability and unit cost analysis. - Complete preliminary and critical designs of end-to-end objective demonstration system. - Conduct two open air demonstrations of limited capability configuration systems that include advanced airborne threats and complex environmental factors. - Select the end-to-end configuration for development and demonstration, addressing convoy on the move against a large raid of variously configured, self-guided sUAS using multiple layered neutralization techniques. - Perform advanced modeling and simulation to validate system performance in operational environment. - Modify and finalize the end-to-end system design to enable operations while on the move by reducing size, weight and power. - Validate graphic user interface that reduces manning false alarm rate, and reaction time. - Conduct final update of affordability and cost analysis. ***FY 2020 Plans:*** - Fabricate and integrate on the move end-to-end demonstration system. - Integrate 3rd party sensors and interceptors to demonstrate interoperability and software openness. - Validate and complete MFP system engagement modeling and simulation tool for transition. - Complete affordability and unit cost analysis for transition. - Conduct open air demonstration that includes realistic threats, performance models, signatures, networks, and environmental factors. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects transition from iterative design phase to final testing.			
Title: Urban Reconnaissance through Supervised Autonomy (URSA)*	5.000	19.000	23.000
Description: *Formerly PDUE: Autonomous Building Search Persistent Deterrence in Urban Environments The goal of the Urban Reconnaissance through Supervised Autonomy (URSA) program is to develop and demonstrate new autonomous agents and techniques that can rapidly discriminate hostile intent and filter out threats during missions ranging from minutes to hours, leveraging natural or created stimuli to elicit behavioral responses among humans in an area. The program seeks to create a system of autonomous ground and air platforms operating in conjunction with U.S. ground forces that monitor an area overtly to detect hostile forces and establish Positive Identification (PID) before any U.S. troops come into contact. Military units follow strict rules of engagement (ROEs) that prescribe an escalation of force appropriate with the level of hostilities and confidence that an individual is engaged in nefarious behavior. This program will establish a Legal, Moral, Ethical (LME) working group comprising multiple individuals (technologists, military, university professors, ethicists, legal experts) to develop an understanding of how escalation of force can and should be appropriately applied in the context of supervised autonomous			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
systems. URSA will explore scenarios and probing behaviors that will enable identifying innocent civilians and individuals with hostile intent. This mission will require the integration and maturation of novel sensors, and unmanned ground and air vehicles which leverage current techniques in perspective and reactive autonomy to navigate cluttered urban environments. URSA will develop new search and probing behaviors to expose human intent and serve as evidence that a potential target is a threat. It will implement new dimensions of evidence such as the human reactions to these probing actions to improve confidence in its decisions, and will build a novel framework for escalating nonlethal force. ***FY 2019 Plans:*** - Conduct trade space analysis regarding sensors, unmanned systems, human behaviors and other dimensions of evidence, and iterative instigation activities. - Initiate development of URSA system architectures. - Initiate development of URSA Integrated Testbed (UIT). - Hold quarterly LME working group meetings and facilitate engagements with technology performers. - Use UIT to perform initial evaluation of URSA system operation and functionality. ***FY 2020 Plans:*** - Demonstrate initial URSA system capabilities in limited, controlled, performer-selected environments. - Continue to develop URSA system architectures. - Assess URSA system capabilities and use cases through UIT environments. - Demonstrate improved URSA system capabilities in limited, controlled, performer-selected environments. - Continue quarterly LME working group meetings and facilitate engagements with technology performers. - Identify URSA end-to-end system capabilities to inform future prototype system development and field experimentation campaign. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects transition from initial development and limited testing to iterative development of capabilities and testing in more challenging environments.			
Title: Subterranean (SubT) Challenge	6.000	22.000	34.000
Description: The DARPA Subterranean (SubT) Challenge will develop novel integrated solutions capable of mapping and navigating complex and dynamic terrains (tunnel systems, urban underground and cave networks); sensors and computation for perception in austere conditions; distributed information sharing in degraded communications environments; and collaborative autonomy enabling extended operations with minimal human interventions. The core objective of the SubT Challenge is to find the solution(s) which best outperforms current approaches for manually and laboriously mapping and searching subterranean environments. Newly developed capabilities will span across four technology focus areas in autonomy, perception, networking,			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
and mobility technologies. The program will increase the diversity, versatility, and robustness of relevant system technologies, capable of addressing the multi-faceted needs of a wide range of environments. Innovations will be explored in the context of a public-facing, broadly inclusive DARPA Challenge. ***FY 2019 Plans:*** - Conduct baseline design, development, and integration, of proposed solutions in the sub-domain of tunnel systems. - Conduct circuit competition in the sub-domain of tunnel systems. - Assess technology maturity and predicted technology trends to identify research and development needs and gaps. - Continue development and refinement of the virtual test bed. ***FY 2020 Plans:*** - Conduct baseline design, development, and integration of proposed solutions in the sub-domain of urban underground. - Conduct circuit competition in the sub-domain of urban underground. - Conduct baseline design, development, and integration of proposed solutions in the sub-domain of cave networks. - Conduct circuit competition in the sub-domain of cave networks. - Continue development and refinement of the virtual test bed. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects execution of multiple vice single sub-domain circuits.			
Title: Rapunzel	-	-	10.000
Description: Urban combat demands that riflemen also serve as combat engineers manipulating their local environment to gain tactical advantage. The urban environment creates unique challenges in providing solutions for mobility, counter-mobility, survivability, and concealment. Every pound that a warfighter wears or carries reduces their mobility and mission effectiveness, and, particularly in urban combat, reduced mobility paradoxically reduces their survivability. The Rapunzel program seeks to enable warfighters to manipulate the urban environment through the application of novel materials research. Rapunzel envisions soldier-borne or vehicle-borne utility-belt style packaged containers, reels, and spools of material that can perform urban engineering tasks such as create bridges between building rooftops, pull down enemy barriers, or provide false targets and concealment. The program will identify those mass-manufactured materials, such as extremely high-tensile strength monofilament that can both provide novel mobility between buildings but also provide novel counter-mobility to enemy vehicles due to their electrical conductance properties. The Rapunzel program will leverage extensive existing research into early developmental materials and invest in the task-based development and packing to provide these materials at appropriate length and size scales for immediate tactical use. ***FY 2020 Plans:***			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Conduct trade space analysis and technical assessments regarding novel materials that are quickly field assembled and fabricated into lightweight components. - Initiate development of mobility, counter-mobility, survivability, and concealment core requirements and systems architectures. - Initiate development of critical manufacturing technologies/approaches and perform baseline demonstrations of existing technologies that can be leveraged to refine program metrics. - Develop operational and technical performance models. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.			
Title: Highly-Networked Dissemination of Relevant Data (3HNDRED) ***Description:*** The goal of the Highly-Networked Dissemination of Relevant Data (3HNDRED) program is to develop and demonstrate an integrated system capable of disseminating relevant, actionable information to the ground warfighter to enable effective accomplishment of mission objectives in a dynamic environment. Heterogeneous sensors, including soldier-borne, vehicle-borne, and manned or unmanned ground/air assets, may be netted together to form a complete picture of an area of interest. A tactical decision engine will receive and process incoming sensor data to form an understanding of mission context, environment, and individual agent role and posture. Based on this knowledge, the tactical decision engine will establish a contextually-relevant personalized operating picture for each node/individual in accordance with their current status and mission goal and then guide action (e.g. heading and urgency) via interface modalities appropriate to the current state. 3HNDRED will assess and integrate hands-free, heads-up interfaces to convey information to the warfighter that can be quickly detected and intuitively understood without cognitive burden, enabling rapid response. 3HNDRED will enable collaborative actions between dismounted and mounted elements across manned and unmanned teams, and support on-the-fly force re-composition, providing an asymmetric advantage to U.S. ground forces. ***FY 2020 Plans:*** - Initiate trade studies to assess 3HNDRED use cases, sensor suite, and interface modalities. - Evaluate multi-modal interface solutions to assess effectiveness across multiple states and posture. - Initiate 3HNDRED tactical decision engine architecture development. - Complete preliminary design and demonstration of tactical decision engine to infer battlefield context and make decisions at scale. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.	-	-	10.000
Title: Tactical Networks of Tunnels (TNT)	-	3.000	10.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Description: The Tactical Networks of Tunnels (TNT) effort, an outgrowth of the Subterranean Challenge program, will explore the development and integration of technologies to investigate, create, and employ technologies that drill/bore, build, and use the underground environment for tactical operations in rapid, secure resupply. TNT will explore creation and utilization of tunneling, drilling, and boring capabilities for systems at multiple scales. The program will examine multiple concepts of operation and will consider creation and use of both temporary tunnels as well as rapid creation of tunnel networks. ***FY 2019 Plans:*** - Initiate trade studies in drilling/boring methods, geological assessments of an underground route, methods, manpower, and infrastructure. ***FY 2020 Plans:*** - Complete initial trade studies. - Initiate development of TNT concept of operation, system architecture, and demonstration test plans. - Begin development of enabling technologies. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects completion of initial studies and transition to development of specific technologies.			
Title: Small Unit Lethality ***Description:*** The Small Unit Lethality program objective is to develop technologies that allow warfighters to clear or empty spaces - manmade or natural - from high standoff distances without destroying them or entering them. The effort will investigate the ability to fill voids of similar space to deny occupation. Materials allowing permanent or temporary denial will both be explored. The program will also develop next generation urban weapon systems organic to dismounted units that provide extended range and tunable effects with greatly minimized impact to a warfighter operator. ***FY 2020 Plans:*** - Conduct trade space analysis and technical assessments regarding effects that fill, neutralize, and clear an intended interior space without destroying structure. - Initiate development of core requirements and systems architectures. - Begin development of Small Unit Lethality critical subsystem technologies. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY2020 increase reflects program initiation.	-	-	6.000
Title: Precision Kinetic Light Strike	5.000	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Description: The Precision Kinetic Light Strike program sought to develop a small, lightweight, guided kinetic weapon for lightweight maneuver forces. Current short-range weapons are used against a variety of target sets using different munitions without the benefit of active guidance. Current long-range weapons are highly effective against a specific target set at range, but are too large or heavy to employ in needed numbers, have a high cost per shot/procurement cost, and often require burdensome logistics or dedicated specialized systems to use. The program goal was to improve on the existing, lightweight unguided munition systems by increasing range, accuracy, and lethality, while reducing cost. These improvements leveraged advances in miniaturization, precision guidance and warheads. Precision Kinetic Light Strike sought to take advantage of commercial technologies whenever possible to provide a low-cost, multi-use, and multi-function precision engagement capability. The Precision Kinetic Light Strike program will significantly increase the combat power of small units with reduced burden, while significantly reducing cost relative to near-peer and peer adversaries.			
Title: Operational Fires ***Description:*** The goal of the Operational Fires (OpFires) program is to develop and demonstrate a novel ground-launched system enabling advanced tactical weapons to penetrate modern enemy air defenses and rapidly and precisely engage critical time sensitive targets. This program seeks to develop an advanced booster capable of delivering a variety of payloads at a variety of ranges. Additional considerations include the need for compatible mobile ground launch platforms enabling integration with existing ground forces and infrastructure, and specific system attributes required for rapid deployment and redeployment. The OpFires program will conduct a series of subsystem tests designed to evaluate component design and system compatibility, and culminate in integrated end-to-end flight tests. Beginning in FY 2019 this effort is funded under PE 0603286E, Project AIR-01.	6.000	-	-
Accomplishments/Planned Programs Subtotals	80.428	109.286	138.040

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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
TT-07: *AERONAUTICS TECHNOLOGY*	-	60.151	50.799	53.119	-	53.119	47.328	59.119	47.528	47.528	-	-

A. Mission Description and Budget Item Justification

Aeronautics Technology efforts will address high payoff opportunities that dramatically reduce costs associated with advanced aeronautical and aerospace systems and/or provide revolutionary new system capabilities for satisfying current and projected military mission requirements. This includes advanced technology studies of revolutionary propulsion, vehicle, and launch concepts, sophisticated fabrication methods, and examination of novel materials and enabling technologies for aeronautic and aerospace system applications. Studies that also fundamentally change the calculus of battle including consideration of a mix of assets, potentially disposable or with limited lifespans, with increased levels of autonomy are included.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Gremlins	31.000	21.799	12.119
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 Unmanned Air Vehicle (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 2019 Plans:*** - Conduct flight validation for launch and recovery capability. - Fabricate and ground test flight-worthy assets. - Conduct flight test demonstrating Gremlins mission objectives. ***FY 2020 Plans:*** - Conduct final flight test demonstrating full recovery capability. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY2020 decrease reflects completion of program following final flight testing.			
Title: Advanced Aeronautics Technologies	2.000	3.000	3.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Description: The Advanced Aeronautics Technologies program will examine and evaluate aeronautical technologies and concepts through applied research. These may include the feasibility studies of novel or emergent materials, devices and tactics for both fixed and rotary wing air vehicle applications, launch vehicles, as well as manufacturing and implementation approaches. The areas of interest range from propulsion to control techniques to solutions for aerospace mission requirements. The result of these studies may lead to the development of new programs or improvement of existing systems. ***FY 2019 Plans:*** - Perform studies to support development of innovative prototypes. - Initiate new studies of novel approaches to improve operating envelopes. - Conduct trade studies of candidate technologies. ***FY 2020 Plans:*** - Perform studies to support development of innovative prototypes. - Initiate new studies of novel technologies to improve speed and range.			
Title: OFFensive Swarm-Enabled Tactics (OFFSET)	10.000	16.000	20.000
Description: The OFFSET program will design, develop, and demonstrate a swarm system architecture to advance the innovation, interaction, and integration of novel swarm tactics. The program will examine enabling technologies for collaborative autonomy for large teams of unmanned systems, including unmanned ground and air capabilities through the use of both virtual, game-based and physical, live-fly testbeds. Key research thrusts include the development of advanced swarm tactics-centered autonomy and development of human-swarm teaming interface technologies. These combined enhancements will facilitate insights and enable employment of these collective systems to address current needs and defeat future threats. The program will consider technologies supporting U.S. ground and air operations, extensible to other operating environments, requiring organic and/or tactical swarm capabilities, and leveraging low-cost, rapidly deploy-able, autonomous system technologies. ***FY 2019 Plans:*** - Conduct capability-based field experimentation events that demonstrate swarm tactics for scaled missions of relevance to urban combat operations. - Explore human-swarm interaction and immersive interfaces of autonomous teams to improve system performance and swarm operator situational awareness. - Integrate systems enablers for enhanced swarm autonomy with advances in associated tactics, primitives, and algorithms. - Initiate swarm sprints for specific technology thrust areas relevant to human-swarm teaming. ***FY 2020 Plans:*** - Demonstrate interfaces for and execution of viable swarm tactics-based courses-of-action. - Continue integration of advanced swarm tactics for capability-based experimentation.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Commence swarm sprints focusing on advancing the virtual environment and augmenting the physical testbed to enable operationally relevant objectives. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects progression to more challenging swarm sprints involving greater experimentation support.			
Title: Control of Revolutionary Aircraft with Novel Effectors (CRANE) ***Description:*** The Control of Revolutionary Aircraft with Novel Effectors (CRANE) program will demonstrate revolutionary improvements in aircraft controls technology. The program will design, build, and flight test an aircraft that is able to fly and maneuver at altitude with no moving control surfaces; relying on state of the art Active Flow Control (AFC) technology. AFC is a broad term that encompasses a range of technology approaches; broadly defined, it is a control mechanism which alters the aerodynamic flow field thru ejection or suction of fluid via an orifice on a lifting body. An emphasis of the program will be on assessing AFC component technologies, risk reduction and experimentation, integrated testing, fabrication and demonstration of a relevant scale novel and innovative aircraft. Technologies, design tools and models developed and demonstrated under this program will be made available to all Services as well as the civilian aerospace sector for application to future air systems development. ***FY 2020 Plans:*** - Conduct technology analysis of AFC components and control scheme. - Complete conceptual design. - Perform risk reduction and experimentation. - Initiate preliminary design of technology demonstrator. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** FY 2020 increase reflects program initiation.	-	-	13.000
Title: CounterSwarmAI ***Description:*** The objective of the CounterSwarmAI program is to develop systems for anticipating and defeating autonomous systems threats of the future. These adversary systems will likely employ advanced artificial intelligence (AI) and machine learning techniques which will inevitably lead to increased complexity and unpredictability of these advanced threats. CounterSwarmAI envisions the development of disruptive technologies across the engagement kill chain, themselves AI-empowered, which directly combat these challenges. CounterSwarmAI decision software will directly interface with future and legacy defensive systems (kinetic and non-kinetic) to rapidly assess, optimally exploit, and efficiently defeat enemy autonomous systems threats. Innovative solutions will enable (a) autonomous systems which provide understanding and vulnerability exploitation through machine learning, (b) an integrated AI-equipped open architecture for multi-faceted swarm defense, and (c) integration and experimentation with live surrogate swarm threats against current fielded defensive systems.	-	-	5.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
FY 2020 Plans: - Demonstrate the applicability of artificial intelligence advances in large-scale autonomous system threats. - Initiate research and development in machine learning advances and adversarial games to identify salient swarm attributes. - Establish baseline technology advances needed for counter swarm engagement decisions. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** FY 2020 increase reflects program initiation.			
Title: Aircrew Labor In-cockpit Automation System (ALIAS) ***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 on-board 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 2019 Plans:*** - Conduct integrated system flight demonstration on operationally representative aircraft with reduced crew operations. - Proceed with system installation and integration on a commercial aircraft with enhanced capabilities. - Continue civil certification process of a commercial aircraft to support flight demonstrations that provide input for reduced crew operations. - Refine human machine interface to support multiple operational mission scenarios. - Conduct optionally piloted vehicle demonstrations on aircraft using integrated system. - Conduct uninhabited flight demonstration with aircraft using integrated system. - Complete system installation and integration on multiple aircraft. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.	17.151	10.000	-
Accomplishments/Planned Programs Subtotals	60.151	50.799	53.119

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-07 / *AERONAUTICS TECHNOLOGY*

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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / *TACTICAL TECHNOLOGY*	Project (Number/Name) TT-13 / *INFORMATION ANALYTICS TECHNOLOGY*	

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
TT-13: *INFORMATION ANALYTICS TECHNOLOGY*	-	119.843	104.610	103.584	-	103.584	107.209	102.155	127.114	132.114	-	-

A. Mission Description and Budget Item Justification

The Information Analytics Technology project develops technology for analyzing data and 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. Benefits sought include deeper understanding of the evolving operational environment tailored to the needs of commanders at every echelon; an enhanced capability to plan, monitor, and control diverse military operations ranging from stability operations to combat; and improvements to the efficiency of core military functions such as national and homeland security, warfighter health and readiness, and defense support of law enforcement and civil authorities. Promising technologies are evaluated in the laboratory and demonstrated in the field to facilitate transition.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Causal Exploration of Complex Operational Environments	21.000	22.000	25.000
Description: The Causal Exploration of Complex Operational Environments program is developing advanced modeling, analysis, simulation, and visualization tools to enable command staffs to rapidly and effectively design, 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 a wide variety of stakeholder groups on civil, economic, and military matters. 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. Current mission design and planning technologies do not adequately model the range of options or the inherent uncertainties. This program will develop tools to create causal, computational models that represent the most significant relationships, dynamics, interactions, and uncertainties of the operational environment including political, military, economic, and social factors. These tools will enable command staffs to design and quantitatively assess potential courses of action in complex operational environments.			
FY 2019 Plans: - Produce an initial prototype system and collaborate with transition partners to assess models for operational environments with complexities such as tribal rivalries, resource shortages, and insurgent activities. - Develop and demonstrate techniques to quantify uncertainty in inputs and models, and refine methodologies and measurements to address dynamically changing models and enable component comparisons. - Expand visualizations and user interfaces to support exploration and refinement of models.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-13 / *INFORMATION ANALYTICS TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Conduct a collaborative experiment in which Army planners and program developers work together to validate and refine the technology on simulated operations. ***FY 2020 Plans:*** - Demonstrate techniques to propagate uncertainty through all parts of the system and enable users to quickly assess the robustness of operational designs. - Develop and demonstrate techniques for maintaining and updating models of operational environments as new information arrives and constraints and guidance evolve. - Integrate language processing and social network analysis technologies to enable real-time sentiment analysis of local populations and quantitative assessment of information operations campaigns. - Conduct collaborative experiments in which military planners and program developers work together to further refine the technology on simulated operations, and an operational evaluation to measure usability and suitability of the system. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase is due to continued work to develop and evaluate technologies, and additional experimentation with military users.			
Title: Data-Driven Discovery of Models (D3M) ***Description:*** The Data-Driven Discovery of Models (D3M) program is developing automated model discovery techniques and tools that enable non-expert users to create empirical models of real, complex processes, and phenomena. The ability to understand the battlespace is driven increasingly by analysis of sensor and open source data. The DoD and the Intelligence Community (IC) are fundamentally limited by a shortage of expert data scientists to construct empirical models that predict behaviors and anticipate contingencies during tactical and strategic planning. D3M will address this need by creating technologies that automate the construction of complex empirical models. D3M technologies will include a library of data modeling primitives that are automatically selectable; automated approaches for composition of complex models from modeling primitives; and intuitive mechanisms for human-model interaction that enable curation of models by non-experts. D3M will focus on the types of empirical modeling problems commonly encountered by the DoD and IC. ***FY 2019 Plans:*** - Enhance modeling primitives and incorporate in integrated toolkits. - Develop and synthesize multi-modal predictive models for unsolved problems, including automated data collection for data augmentation. - Develop question formalization frameworks and specifications for question decomposition to support user-model interaction. - Demonstrate automated composition of complex models in coordination with operators from multiple domains. ***FY 2020 Plans:***	21.000	18.310	17.580

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-13 / *INFORMATION ANALYTICS TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Extend modeling primitives to handle heterogeneous and unstructured data from disparate sources and integrate into toolkits. - Extend composability techniques to enable the construction of data analytic pipelines for complex problems, such as predicting events utilizing a combination of open source intelligence data and data from protected sources. - Formulate measures and models for normal/anomalous behavior of financial markets, and propose indications and warnings to quickly detect and characterize attacks on financial infrastructure. - Collaborate with transition partners from the DoD and IC to perform quantitative assessments of automatically-generated models and to compare these with their internal-expert-developed models on real-world data. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease is the result of development work ramping down and the focus shifting to demonstrations in collaboration with transition partners.			
Title: Modeling Adversarial Activity (MAA)	13.900	17.800	22.000
Description: The Modeling Adversarial Activity (MAA) program is developing technologies for generating high-confidence indications and warnings for weapons of mass terror (WMT) activities. WMT pathways consist of networks or links among individuals, groups, organizations, and other entities that act to promote or enable the development, procurement, possession, transportation, or proliferation of WMTs and related capabilities. Monitoring and controlling WMT pathways is essential to denying access to WMT technology, knowledge, materials, expertise, and weapons. MAA will create graph models reflecting prototypical WMT pathways, develop methods for creating merged activity graphs by aligning entities across multiple intelligence modalities, develop algorithms to match empirical activity graphs with pathway models, and create synthetic data sets at scale to support development and testing of WMT activity detection techniques. MAA technology will transition to the Defense Threat Reduction Agency (DTRA) and the Department of Homeland Security (DHS). ***FY 2019 Plans:*** - Implement graph alignment techniques, and assess strengths and weaknesses of alternative approaches on synthetic data while improving performance and scalability. - Apply techniques for approximate matching of activity graphs, and demonstrate pathway detection on synthetic data. - Create an initial prototype pathway recognizer, and demonstrate the capability to detect modeled WMT activity sequences in synthetic data. - Collaborate with DTRA and DHS to implement techniques in their environments, and to optimize techniques for efficient and timely execution on their computational infrastructure. ***FY 2020 Plans:*** - Explore and evaluate methods to support partial pathway matching and to adapt pathway models. - Develop scaling methods to enable calculations on realistically large graph models.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-13 / *INFORMATION ANALYTICS TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Develop mechanisms for refining prototype pathway recognizers that are generating high rates of false alarms. - Explore methods to tune the end-to-end system to maximize detection and graph matching performance within the DTRA and DHS computational infrastructures. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects continued development of techniques and software for WMT pathway discovery and additional work to integrate these in a prototype pathway recognition system and to evaluate the system on realistically large synthetic data.			
Title: Warfighter Analytics using Smartphones for Health (WASH)	15.000	16.000	18.300
Description: The Warfighter Analytics using Smartphones for Health (WASH) program is developing analytic techniques for continuous and real-time assessment of warfighter physiological health and cognitive state based on the multiple sensor data streams generated by modern smartphones. Recent research in the area of smartphone biometrics has shown the feasibility of measuring user physiological and behavioral parameters for purposes of user authentication. WASH will extend these smartphone biometrics to reliably measure additional user physiological and behavioral parameters relevant to health assessment and the diagnosis of disease. If successful, WASH will produce a mobile application that continuously and reliably assesses warfighter health and combat/mission readiness. WASH is coordinated with the Naval Health Research Center. ***FY 2019 Plans:*** - Develop secure, privacy-preserving, cloud-based data ingest and storage technologies for collecting, organizing, and associating user smartphone, physiological health, and behavioral data. - Develop a mobile application to capture user smartphone data passively and securely, and to compute digital biomarkers. - Perform laboratory assessments of sensitivity and specificity of smartphone-based digital biomarkers for detection and diagnosis of physiological disease and assessment of cognitive state. ***FY 2020 Plans:*** - Conduct periodic audits of the security and privacy controls of the cloud-based data ingest and storage infrastructure, and perform upgrades/improvements as appropriate. - Refine digital biomarker computation to enable discrimination of noise based on context, for example, vehicular versus behavioral movement/vibration. - Perform field assessments of sensitivity and specificity of smartphone-based digital biomarkers for detection and diagnosis of physiological disease and assessment of cognitive state in collaboration with Naval Health Research Center. ***FY 2019 to FY 2020 Increase/Decrease Statement:***			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-13 / *INFORMATION ANALYTICS TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The FY 2020 increase is due to continued work to develop and integrate techniques to analyze user smartphone data, and additional work to evaluate the performance of techniques to assess user physiological health and cognitive state.			
Title: Media Forensics (MediFor) ***Description:*** The Media Forensics (MediFor) program is creating technologies for analyzing media content to determine trustworthiness for military and intelligence purposes. Current approaches to media forensics are labor intensive, requiring analysts and investigators to undertake painstaking analyses to establish context and provenance. The program 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 integrity of open source and captured images and video. Technologies will transition to operational commands and the Intelligence Community (IC). ***FY 2019 Plans:*** - Enhance the effectiveness of forensic algorithms that must operate at large scales and in near-real time. - Develop association methods to track and assess related media assets that are subject to coordinated manipulation by adversaries. - Develop quantitative measures of integrity relevant to diverse needs of government users and specific missions. - Evaluate the effectiveness of the integrated integrity-assessment platform on relevant operational data provided by potential transition partners from the DoD and IC. ***FY 2020 Plans:*** - Scale association algorithms to operate at large scales and in near-real time. - Enhance integrity approaches to be robust to maturing adversarial attack and generative technologies. - Harden integrity indicators to increase robustness, accuracy, and efficiency on large scale datasets. - Demonstrate the full platform prototype in collaboration with government transition partners from the DoD and IC. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease is the result of development work ramping down, and the focus shifting to testing media integrity-assessment techniques and platforms in collaboration with transition partners.	20.880	17.500	5.304
Title: Adapting Cross-domain Kill-Webs (ACK) ***Description:*** The Adapting Cross-domain Kill-Webs (ACK) program will assist military decision makers with rapidly identifying and selecting options for tasking and re-tasking assets within and across organizational boundaries. Based on technologies developed in the Resilient Synchronized Planning and Assessment for the Contest Environment (RSPACE) program (budgeted in PE 0603766E, Project NET-01), ACK will assist users with selecting sensors, effectors, and support elements across military domains (space, air, land, surface, subsurface, and cyber) to form and adapt kill chains to deliver desired effects on targets.	-	8.000	15.400

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-13 / *INFORMATION ANALYTICS TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Today's Command and Control (C2) organizations and processes cannot support multi-domain warfighting concepts, especially during joint operations. ACK will address this challenge by utilizing a decentralized approach to allocating resources to tasks and assigning mission orders to assets, motivated by ideas developed in online commerce, sourcing, and supply chain management, such as bid requests and offers. The impact of ACK will be to accelerate asset re-allocation and assignment decision timelines to be on the order of minutes, and the output of ACK will be automated tools and decision aids to support the selection of the elements of a kill-chain and assignment of roles and responsibilities to each of the elements. Technology developed under this program will be transitioned to the Services. ***FY 2019 Plans:*** - Begin development of the bid request and offer language and message sets for C2 node and virtual liaison coordination across domains. - Create multi-domain capability models as digital artifacts to support evaluations. ***FY 2020 Plans:*** - Develop capability (sensors, weapons, communications, etc.) representations necessary to support the ACK program concept. - Begin development of the supplier-side, virtual liaison offer generation algorithms, and the consumer-side, C2 node algorithms for adjudicating amongst the offered capabilities. - Begin development of a supporting user interface that enables an operator to visualize recommendations and select a final plan. - Begin development of the evaluation test bed. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** FY 2020 increase is due to the implementation of multi-domain modeling and simulation.			
Title: Distributed Battle Management (DBM)	18.063	5.000	-
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 onboard 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 DBM 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-in-the-loop operator approval. DBM technologies are expected to transition to the Services.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-13 / *INFORMATION ANALYTICS TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
FY 2019 Plans: - Use DBM components in a live-fly experiment in support of transition to the services (Navy or Air Force). - Use DBM components (fusion and resource management) in support of multiple live-fly events for the System of Systems Integration Technology and Experimentation (SoSITE) program (budgeted in PE 0603766E, Project NET-01) incorporating increased complexity in terms of new platforms and payloads and overall scale. - Expand the number of flight systems modeled in DBM system. - Demonstrate the capability to support air-to-air and air-to-ground tactics simultaneously. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Title: Memex ***Description:*** The Memex program developed search technologies to revolutionize the discovery, organization, and presentation of domain-specific content. Earlier search technologies were limited in search query format, retrieved content organization, and infrastructure support, and they imposed an iterative search process that was time-consuming and inefficient, producing only a fraction of the available information. Memex created a new domain-specific search paradigm that discovers relevant content and organizes it in ways that are more immediately useful to specific missions and tasks. In addition, Memex domain-specific search engines extend the reach of current search capabilities to the deep web and non-traditional content. Memex technologies enable the military, government, and commercial enterprises to find and organize mission-critical information on the Internet and in large intelligence repositories. Mission areas addressed by Memex included counter-terrorism, counter-drug, anti-money-laundering, and anti-human-trafficking, with transition partners from DoD and other U.S. Government activities.	5.000	-	-
Title: Network Defense ***Description:*** The Network Defense program developed technologies to detect network attacks. 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 can make it possible to identify trends and patterns visible only when the data is viewed as a whole. Network Defense developed 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 can enhance information security in both the government and commercial sectors.	5.000	-	-
Accomplishments/Planned Programs Subtotals	119.843	104.610	103.584

C. Other Program Funding Summary ($ in Millions)

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-13 / *INFORMATION ANALYTICS TECHNOLOGY*

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.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602715E / *MATERIALS AND BIOLOGICAL TECHNOLOGY*

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	191.880	208.898	223.976	-	223.976	245.397	242.845	265.429	279.273	-	-
MBT-01: *MATERIALS PROCESSING TECHNOLOGY*	-	85.376	95.676	108.803	-	108.803	129.628	130.738	151.839	161.839	-	-
MBT-02: *BIOLOGICALLY BASED MATERIALS AND DEVICES*	-	106.504	113.222	115.173	-	115.173	115.769	112.107	113.590	117.434	-	-

A. Mission Description and Budget Item Justification

The Materials and Biological Technology Program Element is budgeted in the Applied Research Budget Activity because its objective is to develop materials and biological 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, fabrication and processing techniques, models, 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 technology areas including manufacturing, electronics, sensors, optics, and complex and autonomous systems.

The Biologically Based Materials and Devices project will leverage the growing and pervasive influence of the biological sciences for the development of new DoD capabilities. Contained in this project are thrusts that apply biology's unique fabrication and manufacturing capabilities to produce and detect novel DoD relevant chemicals, materials at scale, and devices for overmatch. Example projects include analyzing biological threats at the cellular and molecular level, mitigating the effect of threat agents on deployed warfighters, and developing remote, persistent sensor systems to detect terrestrial and maritime threats. This project also includes efforts to develop novel technologies for maintaining human combat performance.

B. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	224.440	226.898	224.572	-	224.572
Current President's Budget	191.880	208.898	223.976	-	223.976
Total Adjustments	-32.560	-18.000	-0.596	-	-0.596
• Congressional General Reductions	-22.544	-18.000			
• 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	-0.667	0.000			
• SBIR/STTR Transfer	-9.349	0.000			
• TotalOtherAdjustments	-	-	-0.596	-	-0.596

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide I* BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602715E *I MATERIALS AND BIOLOGICAL TECHNOLOGY*

Change Summary Explanation

FY 2018: Decrease reflects Congressional reduction, SBIR/STTR transfer and reprogrammings.
FY 2019: Decrease reflects Congressional reduction.
FY 2020: Decrease reflects minor program repricing.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
MBT-01: *MATERIALS PROCESSING TECHNOLOGY*	-	85.376	95.676	108.803	-	108.803	129.628	130.738	151.839	161.839	-	-

A. Mission Description and Budget Item Justification

The major goal of the Materials Processing Technology project is to develop novel materials, fabrication and processing techniques, models, 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 technology areas including manufacturing, electronics, sensors, optics, and complex and autonomous systems.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Materials Processing and Manufacturing	17.997	27.678	29.039

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 parts and systems. Constantly changing specifications for DoD platforms combined with recent manufacturing advances, such as 3D printing and manufacture on demand, drive a need for greater efficiency in development and design cycles as well as scalable and reconfigurable manufacturing processes that incorporate advanced materials with superior properties. Research within the Materials Processing and Manufacturing thrust is focused on achieving the following capability objectives: (1) scalable processes to assemble fully 3D devices that include nanometer- to micron-scale components; (2) processes that yield new materials, materials capabilities and parts that cannot be made through conventional processing approaches; (3) efficient, low volume manufacturing; (4) approaches that reduce manufacturing complexity through new material feedstock formats with reconfigurable processing techniques; and (5) material processing that enhances platform survivability in extreme environments.

FY 2019 Plans:

- Demonstrate pilot-scale production of tailorable, high-performance carbon fiber-based feedstock that meets or exceeds state-of-the-art aerospace materials capability.
- Demonstrate that a multifunctional element can be incorporated into the feedstock while maintaining performance.
- Demonstrate that a multifunctional component can be formed without degradation of performance in either the structural or the functional component.
- Investigate methods for the scale-up of nano- and micro-assembly techniques.
- Test and evaluate retention of nanoscale properties when assembly process is scaled-up.
- Initiate development of new models for improved understanding of physical, chemical and mechanical properties of high entropy materials.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Identify new processing approaches for manufacturing high temperature materials in large and/or complex shapes. ***FY 2020 Plans:*** - Explore approaches that leverage new computational and manufacturing tools to fabricate large complex structures for enhanced platform survivability in harsh environments. - Leverage recent breakthroughs in metrology to characterize atomic- through meso-scale material behaviors. - Develop model guided testing tools to validate the behavior of new materials under extreme environmental conditions. - Investigate mechanical/physical/chemical properties of high entropy alloys for applications in extreme environments. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects minor program repricing.			
Title: Functional Materials and Devices	10.228	19.215	20.164
Description: The Functional Materials and Devices thrust is developing advanced materials, components and systems to improve device performance for DoD sensing, imaging and communication applications. One focus of this thrust involves development of advanced transductional materials that convert one form of energy to another for DoD-relevant applications in areas such as thermoelectrics. While promising transduction materials are known for a variety of applications, integration into devices has not been realized. Another focus area is the development of physics based models that predict material behavior when illuminated by high peak power electromagnetic interference. A third focus area involves development of new multi-functional materials and device designs that will radically decrease the size, weight and power requirements of neutron and gamma sources for high-resolution neutron, gamma and x-ray imaging. Such devices should enable fieldable detection units for non-destructive evaluation of parts, detection of explosives and other DoD-relevant targets. ***FY 2019 Plans:*** - Evaluate compositions, fabrication processes and applications of high-performance textured piezoelectric materials. - Perform final integrated compact neutron source prototype testing. - Explore innovative design concepts for intense, mobile, mono-energetic gamma sources. - Identify component technologies with potential for enabling intense, mobile, mono-energetic gamma sources for elemental imaging and advanced diagnostics. - Initiate development of advanced physics-based models for predicting material behaviors under high peak electromagnetic power. ***FY 2020 Plans:*** - Demonstrate performance of compact gamma source component technologies. - Initiate efforts to integrate component technologies into a compact, mono-energetic gamma source prototype.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Validate experimentally the ability of physics-based models to predict material behaviors under high peak electromagnetic power. - Initiate efforts to incorporate physics-based models in device design tools to improve operational robustness in the presence of noisy electromagnetic environments. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects minor program repricing.			
Title: Reconfigurable Systems	20.280	12.791	21.058
Description: In the Reconfigurable Systems thrust, new approaches are being developed to enable more rapid and robust adaptation of defense systems and systems-of-systems to changing mission requirements and unpredictable environments. This includes development of capabilities across sensing, perception, planning and control for autonomous, high-speed operation in cluttered environments without Global Positioning System (GPS) information. This also includes development of capabilities to manipulate and control adversary sensory perception and/or situational awareness. Additional work in this thrust focuses on how sensing systems and military systems-of-systems are designed for real-time resilient response to dynamic, unexpected signals and contingencies. Research is developing a more unified view of system behavior that allows better understanding and exploitation of complex interactions among components, including development of formal mathematical approaches to complex adaptive system composition and design. These capabilities will impact autonomous systems and systems-of-systems, including those that involve humans, in a variety of DoD-relevant contexts. ***FY 2019 Plans:*** - Develop capability for self-diagnosis of current system performance from arbitrary set of sensors, behaviors, and constraints. - Demonstrate closed-loop single functional recomposition from a set of sub-system components. - Demonstrate redesign of system function to attrition and environmental change. - Initiate efforts to determine conditions in which special effects can manipulate human and/or machine sensory inputs to control perception. ***FY 2020 Plans:*** - Demonstrate redesign of coordinated functions to achieve maximum resilience. - Demonstrate dynamic adaptive response to achieve system re-design. - Demonstrate system design for adaptive response to a co-evolving threat coupled to attrition and environment change. - Investigate potential for altering human and/or machine perception by leveraging new breakthroughs in projection technologies across the electromagnetic spectrum. ***FY 2019 to FY 2020 Increase/Decrease Statement:***			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
The FY 2020 increase reflects expanded research in the development of capabilities to manipulate and control adversary sensory perception and situational awareness.			
Title: Accelerating Discovery and Innovation	16.437	10.630	11.155
Description: The Accelerating Discovery and Innovation thrust is developing new approaches, tools and technologies to speed the pace of scientific discoveries and technological innovations from idea generation and fundamental research through integration of technologies into fieldable products and systems in production. The path from idea generation to a discovery is a lengthy, complex process involving many unpredictable steps, cycles and stages across fundamental and applied research and development. Research in this thrust is focused on developing and implementing strategies to address many of the challenges and bottlenecks inherent along this path and to speed the rate at which an idea can be advanced into a concrete capability. Specific approaches include advanced multiplayer gaming technologies to catalyze development of new technology concepts, development of tools for data collection and visualization to accelerate fundamental and applied research, and strategies to understand how seemingly benign commercially available technologies may be converted or combined into threats to military operations, equipment or personnel. ***FY 2019 Plans:*** - Develop software tools to facilitate an analytic multi-disciplinary conversation to facilitate the collective understanding and potential implications of emerging science and technology. - Develop software systems to aid in identifying emerging science and technology concepts and applications based on existing understanding. - Design and build additional sets of interoperable kits for military applications from easily obtainable components. - Design and build a highly capable reconnaissance-strike system that integrates the interoperable kits. - Test the reconnaissance-strike system(s) with military partners. - Investigate the understanding of what enables projected animations to be perceived as real. ***FY 2020 Plans:*** - Create software tools to expedite the synthesis of multi-disciplinary conversations about emerging science and technology into evidence supported research proposals. - Develop tools that allow for incorporation of the needs of research and development requirement generators with the capabilities of research and development performers. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects minor program repricing.			
Title: Multi-Scale Modeling	-	14.362	27.387

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020

Description: The Multi-Scale Modeling thrust, an outgrowth of the Reconfigurable Systems thrust, is developing advanced, multi-physics models that can predict the effect of disturbances and/or perturbations in the space environment in order to inform operational decisions based on current space environment conditions. Current space environment models are limited to predicting long term climatic averages or regularly occurring phenomena and do not fully account for coupling effects where perturbations in one region of the space environment may produce disturbances in another region. Approaches for addressing these limitations under the Multi-Scale Modeling thrust include the following: (1) development of observation driven/first-principles theory of magnetosphere-ionosphere-thermosphere coupling; (2) creation of an extensible assimilation framework for unifying space environment monitoring systems and data; and (3) non-traditional space environment measurement approaches. These developments will ensure the accuracy and spatiotemporal resolution of space weather models and is sufficient to enable prediction of operationally relevant perturbations and disturbances in the space environment.

FY 2019 Plans:

- Initiate efforts to explore advanced methods and tools, such as hybridized particle/fluid methods, adaptive mesh computational techniques, and vector processing, to extend capabilities of state-of-the-art "nowcast" space weather predictions.
- Initiate efforts to develop fully coupled space environment model suite capable of assimilating high resolution 4D data (observed and synthetic).
- Initiate development of an extensible framework to unify traditional and non-traditional ionospheric measurements, both terrestrial and in-situ.
- Initiate development of multi-physics models that can predict ionospheric perturbations, such as plasma "holes" and acoustic shock waves, associated with various air and space platform trajectories.

FY 2020 Plans:

- Identify promising approaches that dynamically utilize computational architectures (adaptive meshes, vector processing, cloud architecture) to drive down space weather prediction times to the nowcast (hourly) regime.
- Demonstrate in simulation the ability to predict and track space weather phenomena with scale lengths as small as one hundred kilometers.
- Demonstrate an extensible assimilation framework capable of processing data sources from at least two major space environment observations networks in less than fifteen minutes.
- Demonstrate in simulation the ability of multi-physics models to predict ionospheric perturbations, such as plasma "holes" and acoustic shock waves, associated with various air and space platform trajectories.

FY 2019 to FY 2020 Increase/Decrease Statement:

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
The FY 2020 increase reflects expansion into demonstrations of the abilities to predict space weather phenomena and ionospheric perturbations.			
Title: Chemical Processing for Force Protection	20.434	11.000	-
Description: Research in this thrust is focused on the development of new chemical approaches and technologies across a broad spectrum of DoD needs. One area involves development of innovative approaches for scalable small molecule synthesis coupled with predictive tools for route design, possibly offering a new strategy to discover how to make new molecules such as pharmaceuticals and explosives. Another focus combines existing strategies for destruction of chemical agents with development of new processing methods to provide a remediation system that can process any chemical agent at the site of storage. In addition, investments in this thrust will advance chemical characterization, information management and analysis, and automation. ***FY 2019 Plans:*** - Demonstrate continuous flow synthesis of a molecule requiring a convergent approach (e.g., synthesis and subsequent combination of two intermediates). - Adapt continuous flow technology to low cost, portable chemical reactors for distributed manufacturing. - Develop a computational map of synthetic capabilities for existing modules that outlines the potential suite of molecules that can be generated in the automated device. - Demonstrate rapid search of reaction conditions (1,000s of reactions per hour) and initiate integration of these data into route design algorithms. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Accomplishments/Planned Programs Subtotals	85.376	95.676	108.803

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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
MBT-02: *BIOLOGICALLY BASED MATERIALS AND DEVICES*	-	106.504	113.222	115.173	-	115.173	115.769	112.107	113.590	117.434	-	-

A. Mission Description and Budget Item Justification

The Biologically Based Materials and Devices project will leverage the growing and pervasive influence of the biological sciences for the development of new DoD capabilities. Contained in this project are thrusts that apply biology's unique fabrication and manufacturing capabilities to produce and detect novel DoD relevant chemicals, materials at scale, and devices for overmatch. Example projects include analyzing biological threats at the cellular and molecular level, mitigating the effect of threat agents on deployed warfighters, and developing remote, persistent sensor systems to detect terrestrial and maritime threats. This project also includes efforts to develop novel technologies for maintaining human combat performance.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Enhancing Neuroplasticity	19.430	15.222	14.543

Description: The DoD needs tools to rapidly and effectively train military personnel in multifaceted and complex tasks. The Enhancing Neuroplasticity program is exploring and developing peripheral nerve stimulation methods and non-invasive devices to promote synaptic plasticity for improved learning paradigms. 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 for military personnel. Once successfully identified, the underlying mechanisms of targeted plasticity training can be applied to a broad range of cognitive skill training within the DoD, including foreign language learning, or data and intelligence analysis.

FY 2019 Plans:
- Compare effects of various nerve stimulation targets on brain neurophysiology and learning rate in animal models.
- Assess the combined impacts of neuromodulator receptor optimization with peripheral nerve stimulation to improve cognitive, motor, or sensory task performance in animal models.
- Determine efficacy of various biomarkers to validate target nerve stimulation in animal models.
- Initiate human studies of non-invasive nerve stimulation on learning.
- Identify technologies capable of in vivo characterization of human microbiome systems at the scale of microbial interactions.
- Characterize how information is passed between microorganisms (microbial communicome) and how that information is passed through generations and their host locations, including gut, brain, and skin.

FY 2020 Plans:
- Utilize biomarkers to guide effective engagement of nerve targets in human studies.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Evaluate combined efficacy of pharmacological neuromodulation with peripheral nerve stimulation for learning in human trials. - Assess the longevity of effects of targeted peripheral nerve stimulation on cognitive, motor, or sensory task performance. - Demonstrate statistically valid improvement in performance and/or decrease in the time to achieve proficiency after pairing peripheral nerve stimulation with training. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects minor program repricing.			
Title: Genome Protection Technologies ***Description:*** The Genome Protection Technologies program is developing advances in critical efforts to generate a biodefense capability to control, counter, and reverse the effects of accidental or malicious misuse of gene editing technologies. This research will investigate new approaches for developing tunable controls to enable the safe and predictable use of synthetic genes and pathways. Additional work will develop protecting measures to prevent or limit unintended genome editing or engineering and develop new tools to recall or reverse engineered changes. Advances within this program will ensure that the U.S. remains at the vanguard of this now widespread, rapidly advancing field that poses potential national security threats due to the large-scale democratization of gene editing technologies. ***FY 2019 Plans:*** - Conduct laboratory animal model testing for safety and efficacy of small molecule and genetic countermeasures. - Use computational models to evaluate efficacy, stability, and fitness of gene editing controllers and countermeasures. - Demonstrate efficacy, stability, and fitness of gene editing controllers and countermeasures in laboratory animal models. - Characterize failure modes of gene editor controllers and countermeasures. ***FY 2020 Plans:*** - Conduct advanced in vivo testing of genome editors to include characterization of off-target effects, failure modes, target editing efficiency, and stability. - Design safety measures and characterize toxicity and immunogenicity of genome editors. - Determine safety and efficacy and characterize off-target effects of genome editor countermeasure candidates in vivo. - Incorporate empirical data such as gene flow, fitness, generational stability, and failure modes into advanced computational models. - Demonstrate the ability to revert or eliminate target genes in organisms in laboratory environments. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects minor program repricing.	11.844	17.357	17.150
Title: Defend Against Crop System Attack	10.700	14.018	13.718

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
Description: The Defend Against Crop System Attack program is developing a platform technology aimed at increasing the speed of DoD response to state or non-state actor release of biological threats directed at our crop systems. Conventional methods to defend against these threats are generally slow and ineffective. This program will leverage recent advances in molecular and synthetic biology to enable rapid delivery of gene therapies to plants for large-scale trait modification, improving resilience against adversary attack or emerging natural threats. Research within this program will develop an agnostic, scalable capability for protecting entire crop systems from emerging threats posed to food security by U.S. adversaries. ***FY 2019 Plans:*** - Scale deployment of flexible plant transformation platforms in a controlled greenhouse setting. - Initiate integration of novel and existing failsafe capabilities for the trait delivery platform. - Investigate new approaches to increase the efficacy of genetic transmission. - Demonstrate predictable and repeatable transmission of genetic materials to plants. ***FY 2020 Plans:*** - Ensure two week-long stable viral transformation resulting in gene-based protection in plant target. - Determine adequate virus concentration to achieve adult plant transformation. - Perform risk mitigation of potential delivery challenges within complex laboratory environments. - Integrate virus delivery approach to achieve adult plant transformation. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects minor program repricing.			
Title: Persistent Terrestrial Living Sensors	3.000	12.582	13.174
Description: The Persistent Terrestrial Living Sensors program is developing engineered biological sensor platforms capable of detecting land-based threats (e.g., chemicals, radiation, explosives) and relaying unique signals to existing DoD ground, air, and space assets. Unlike conventional methods that passively monitor threats and are limited by sensor energy needs, these biological sensors are effectively energy independent, increasing the potential for wide distribution and environmental robustness. Resulting platforms developed within this program will enable a variety of remote, persistent monitoring and reporting capabilities to address threat scenarios relevant for national security, including detecting improvised explosive devices (IEDs) and protecting infrastructure. These sensors will provide a flexible suite to complement conventional sensor systems within the DoD. ***FY 2019 Plans:*** - Develop a quantitative model to guide plant-based sensor resilience and environment flexibility. - Demonstrate the feasibility of combining high-specificity detection traits with physiological response traits by first exploring plant cell expression and quantitative modeling, and then by altering the physiology of plants.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Begin production of plants with individual sense and report traits. - Investigate methods to use soil-based microorganisms to sense subterranean events and propagate signals to the soil surface. ***FY 2020 Plans:*** - Demonstrate genetic modification of plant-expressed sensory proteins associated with DoD-relevant compounds. - Demonstrate genetic modification of plant-expressed reporting signals at detectable levels. - Identify internal plant resource issues that will have to be addressed to develop a real-world detection platform. - Identify external biotic and abiotic challenges that need to be addressed to avoid practical use of plants as sensors. - Test methods for stand-off detection of signals produced by microorganisms in response to subterranean sensing. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects minor program repricing.			
Title: Preemptive Expression of Protective Alleles (PREPARE)*	8.510	15.712	16.097
Description: *Formerly Transient CBRN Threat Defense The Preemptive Expression of Protective Alleles (PREPARE) program is creating a transient, near immediate prophylaxis to protect military personnel and civilians against public health and national security threats. Currently, protection against chemical, biological, and radiological threats relies on physical barrier technology. This program will include research to develop novel transient and reversible gene modulator therapies to bolster intrinsic host defenses. Work within this project will provide novel solutions that extend beyond the DoD's limited protective capabilities to respond to re-emerging, newly emerging, or engineered threats. ***FY 2019 Plans:*** - Begin development of bioinformatics tools and validation methods that will improve the design and specificity of transient gene therapy strategies. - Demonstrate genetic basis for cellular stress resistance in vitro. - Characterize effective delivery tools for gene modulators that enable stress resistance. - Characterize specificity of transient gene therapy in animal models. - Demonstrate effectiveness of stress resistance constructs to specific threats. - Initiate development of platform capabilities for scalable and adaptable threat response platform. ***FY 2020 Plans:*** - Demonstrate multiplexed targeting of multiple cellular resistance genes to confer resistance to multiple threats. - Demonstrate and optimize specificity and duration of modulation of gene modulators in animal models. - Optimize delivery tool specificity for gene modulators.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Demonstrate target-agnostic platform that can address multiple threats using a common set of gene modulation and delivery components. - Investigate timing of optimal countermeasure administration to maximize therapeutic and prophylactic performance. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects minor program repricing.			
Title: Persistent Aquatic Living Sensors	-	18.799	27.066
Description: The Persistent Aquatic Living Sensors program will develop novel capabilities to sense and surveil submersibles (e.g., submarines, unmanned underwater vehicles) and divers in littoral waters using living organisms present in the environment. This effort will focus on characterizing marine biological behavior in response to targets of interest and developing the hardware, software, and algorithms that will translate organism behavior into DoD actionable information. By harnessing the unique capabilities of biology, including adaptation, response, and replication, work in this program will enable persistent dominance in contested waters. Results from this research will enhance security for maritime activities and provide DoD naval operations with new sensing paradigms to complement current sensor technologies used in traditionally challenging regions across the world. ***FY 2019 Plans:*** - Investigate organism response to targets of interest in a laboratory environment using benchtop instrumentation. - Initiate research to convert organism response into robust sensing system by developing algorithms to classify organism response in relation to targets. - Research new reporting schemes to communicate signal detection and actionable information to existing DoD systems. ***FY 2020 Plans:*** - Characterize biological responses to targets and confounders at greater distances and in more realistic environments. - Investigate approaches to evoke biological responses in marine organisms. - Harden engineered components for persistent deployments, and perform validation testing on system endurance. - Develop fully integrated seaworthy prototype combining biology and engineered components. - Demonstrate system ability to detect and classify targets and confounders in ecosystem-style aquaria or open waters, analyze results, and produce alerts via satellite link. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects ongoing research and development efforts, construction of seaworthy prototype, and prototype demonstration, as well as new efforts initiated to evoke biological responses in marine organisms.			
Title: Expanding Human Resiliency	-	-	13.425

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
Description: The Expanding Human Resiliency program aims to maximize warfighter performance and resiliency by leveraging the signals of the human microbiome to improve physiology. This program will develop new technologies to control and manipulate the microbiome to enable peak human performance. Current state-of-the-art approaches are focused on metagenomics to inventory and categorize the microbes in a given sample. In order to have more precise and on-demand control of the human microbiome, technologies will be developed to elucidate the complex interactions between the microorganisms and their human host as well as the interactions between consortia of adapted and evolved microorganisms. Additional work will be performed to facilitate human functions (e.g., immunity to disease, metabolic performance, tolerance to chemical exposure, etc.) and behaviors (e.g., mood, decision making, ability to work as a cohesive team, etc.) using specific microbial consortia living in the gastrointestinal tract, respiratory tract, skin or mouth. Advances in this area will both develop novel technologies to interrogate complex microbial communities in human systems and discover ways to beneficially harness microbiomes to expand warfighter resiliency and performance. ***FY 2020 Plans:*** - Investigate ways to improve methods for interpretation and prediction of microbial interactions and their ability to regulate host function. - Initiate testing of methods to alter chemical production by microbiomes. - Begin longitudinal studies to track host function and behavior with changes in the microbiome. - Begin development of initial microbiome modulation approaches and assess host functional response. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.			
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 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-	17.020	6.298	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
cycle and enabling the ability to rapidly assess and improve designs. Success is predicated on 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, materials precursors, and polymers (those tolerant of harsh environments). This program has basic research efforts funded in PE 0601101E, Project TRS-01. ***FY 2019 Plans:*** - Demonstrate a fully automated infrastructure pipeline capable of prototyping and generating DoD-relevant molecules. - Demonstrate ability to scale production of molecules from multi-gram to kilogram scale using biology. - Investigate methods to generate molecules that have not been previously synthesized using traditional chemistry. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Title: Adaptive Immunomodulation-Based Therapeutics	16.212	13.234	-
Description: The Adaptive Immunomodulation-Based Therapeutics program is developing platform technologies to interrogate and define the biological pathways that will enhance operational readiness for DoD personnel. This program will aid the warfighter by improving immune response, minimizing inflammation, and restoring critical organ function post trauma. 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 harness the bioelectric code, enabling targeted therapy without the need for pharmacological products, ultimately reducing logistical requirements. An additional approach involves characterizing the host response in patients with severe infections, which provides a quantitative framework to guide therapy. Algorithms will be developed to evaluate and predict various physiological conditions for military personnel. Advances made under the Adaptive Immunomodulation-Based Therapeutics program will improve the response capabilities against severe biological threats and offer new avenues for treating disease or organ function to improve force readiness. ***FY 2019 Plans:*** - Quantify on-target responses to neurostimulation to validate feedback biomarkers, evaluate therapeutic benefit, and demonstrate circuit specificity. - Implement computational models of integrated neuromodulation and biomarker signaling for feedback control of health status. - Demonstrate sustained functionality of novel bio-interfaces for neuromodulatory control of health status in animal models.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Initiate clinical studies of feedback-controlled neuromodulation system to treat inflammation, pain, and the effects of Post-traumatic stress disorder (PTSD). ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Title: BioDesign ***Description:*** BioDesign employed system engineering methods in combination with advances in biological and chemical technologies to create novel methods for threat response. This thrust developed 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 permit rapid assessment of the impact of known or unknown threats on identified biomolecules and cell function. Successful research in this thrust both reduced the time required to understand the mechanism of action for new pharmaceutical compounds and enhanced response capabilities for emerging and engineered threats.	9.747	-	-
Title: Biological Robustness in Complex Settings (BRICS) ***Description:*** The Biological Robustness in Complex Settings (BRICS) program developed innovative approaches to engineer forensic microbial systems, creating unique microbial signatures for environmental forensic operations and modulation of host function. Integrating the fundamental component technologies developed under PE 0601101E, TRS-01, this program focused on engineering microbial communities, detection signatures, and mechanisms of robustness. This deeper knowledge helped assemble the constructs needed for new microbial systems that could be used for DoD relevant applications including forensics and warfighter health and performance.	10.041	-	-
Accomplishments/Planned Programs Subtotals	106.504	113.222	115.173

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.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	283.180	348.847	332.192	-	332.192	340.000	369.456	386.366	392.366	-	-
ELT-01: *ELECTRONIC TECHNOLOGY*	-	283.180	115.208	135.882	-	135.882	147.300	165.556	182.156	188.156	-	-
ELT-02: *BEYOND SCALING TECHNOLOGY*	-	0.000	233.639	196.310	-	196.310	192.700	203.900	204.210	204.210	-	-

A. Mission Description and Budget Item Justification

The Electronics Technology 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. The Electronics Technology Project focuses on turning basic advancements into the underpinning technologies required to address critical national security issues and to enable an information-driven warfighter.

Advances in microelectronic device technologies continue to significantly benefit improved weapons effectiveness, intelligence capabilities, and information superiority. The Electronic Technology project therefore supports continued advancement in microelectronics, including electronic and optoelectronic devices, Microelectromechanical Systems (MEMS), semiconductor device design and fabrication, and new materials and material structures. Particular focuses of this work include reducing the barriers to designing and fabricating custom electronics and exploiting improved manufacturing techniques to provide low-cost, high-performance sensors. Programs in this project will also greatly improve the size, weight, power, and performance characteristics of electronic systems; support positioning, navigation, and timing in GPS-denied environments; and develop sensors more sensitive and robust than today's standards.

The Electronic Technology project will also investigate the feasibility, design, and development of powerful devices, including non-silicon-based materials technologies to achieve low-cost, reliable, fast, and secure computing, communication, and storage systems. Rapid design and utilization of these new technologies will be a critical focus of ELT-01, as DoD looks for mechanisms to speed the development and fielding of advanced technologies.

This project has six major focus areas: Electronics, Photonics, MicroElectroMechanical Systems, Architectures, Algorithms, and other Electronic Technology research.

The Beyond Scaling Technology project recognizes that, within the next decade, the continuous pace of improvements in electronics performance will face the fundamental limits of silicon technology. These limits present a barrier that must be overcome in order for progress to continue. This project will therefore pursue potential electronics performance advancements that do not rely on Moore's Law but instead leverage circuit specialization, to include materials, architectures, and designs intended to suit a specific need. In addition, the Beyond Scaling Technology Project recognizes that the envisioned electronics specialization will require proper security safeguards. Electronics advancements must simultaneously make progress in performance and secure the foundation on which our digital infrastructure relies. Programs within the Beyond Scaling project will look at reducing barriers to making specialized circuits in today's silicon hardware and significantly increase the ease with which DoD can design, deliver, and eventually upgrade critical, customized electronics. Programs will also explore alternatives to traditional circuit architectures,

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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for instance by exploiting vertical circuit integration to optimize electronic devices and by incorporating novel materials, and explore techniques for securing DoD and commercial data and hardware.

B. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	295.447	333.847	307.073	-	307.073
Current President's Budget	283.180	348.847	332.192	-	332.192
Total Adjustments	-12.267	15.000	25.119	-	25.119
• Congressional General Reductions	0.000	-15.000			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	30.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	0.000	0.000			
• SBIR/STTR Transfer	-12.267	0.000			
• TotalOtherAdjustments	-	-	25.119	-	25.119

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2018	FY 2019
Project: ELT-02: *BEYOND SCALING TECHNOLOGY*		
Congressional Add: *DARPA Electronics Resurgence Initiative*	-	30.000
Congressional Add Subtotals for Project: ELT-02	-	30.000
Congressional Add Totals for all Projects	-	30.000

Change Summary Explanation

FY 2018: Decrease reflects SBIR/STTR transfer.

FY 2019: Increase reflects Congressional adjustments.

FY 2020: Increase reflects initiation of the Intelligent Spectroscopic & Temporal Fusion (INSPECT) and Instinctual RF programs in FY 2020.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602716E / *ELECTRONICS TECHNOLOGY*	Project (Number/Name) ELT-01 / *ELECTRONIC TECHNOLOGY*	

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
ELT-01: *ELECTRONIC TECHNOLOGY*	-	283.180	115.208	135.882	-	135.882	147.300	165.556	182.156	188.156	-	-

A. Mission Description and Budget Item Justification

Advances in microelectronic device technologies continue to significantly benefit improved weapons effectiveness, intelligence capabilities, and information superiority. The Electronic Technology project therefore supports continued advancement in microelectronics, including electronic and optoelectronic devices, Microelectromechanical Systems (MEMS), semiconductor device design and fabrication, and new materials and material structures. Particular focuses of this work include reducing the barriers to designing and fabricating custom electronics and exploiting improved manufacturing techniques to provide low-cost, high-performance sensors. Programs in this project will also greatly improve the size, weight, power, and performance characteristics of electronic systems; support positioning, navigation, and timing in GPS-denied environments; and develop sensors more sensitive and robust than today's standards.

The Electronic Technology project will also investigate the feasibility, design, and development of powerful devices, including non-silicon-based materials technologies to achieve low-cost, reliable, fast, and secure computing, communication, and storage systems. Rapid design and utilization of these new technologies will be a critical focus of ELT-01, as DoD looks for mechanisms to speed the development and fielding of advanced technologies.

This project has six major focus areas: Electronics, Photonics, MicroElectroMechanical Systems, Architectures, Algorithms, and other Electronic Technology research.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: High power Amplifier using Vacuum electronics for Overmatch Capability (HAVOC)	18.000	6.000	5.000
Description: The High power Amplifier using Vacuum electronics for Overmatch Capability (HAVOC) program seeks to develop compact Radio Frequency (RF) signal amplifiers for air, ground, and ship-based communications and sensing systems. HAVOC amplifiers would enable these systems to access the high-frequency millimeter-wave portion of the Electromagnetic (EM) spectrum, facilitating increased range and other performance improvements. Today, the effectiveness of combat operations across all domains increasingly depends on DoD's ability to control and exploit the EM spectrum and to deny its use to adversaries. However, the proliferation of inexpensive commercial RF sources has made the EM spectrum crowded and contested, challenging our spectrum dominance. Operating at higher frequencies, such as the millimeter-wave, helps DoD to overcome these issues and offers numerous tactical advantages such as high data-rate communications and high resolution and sensitivity for radar and sensors. Opportunities for transferring HAVOC technology to the Services will be identified during the execution of the early phases of the program. 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 2019 Plans:			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*	**Project (Number/Name)** ELT-01 / *ELECTRONIC TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Complete the design, fabrication, and testing of higher power, higher duty cycle devices to meet Phase 2 program metrics. - Research novel techniques and technologies to address greater thermal management requirements of higher power devices. - Fabricate and test higher power, higher duty cycle devices to meet Phase 3 program metrics. ***FY 2020 Plans:*** - Transition designs and prototypes to the Services. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects the program transitioning from fabrication and testing of devices to transition.			
Title: Precise Robust Inertial Guidance for Munitions (PRIGM)	18.500	10.500	8.000
Description: The Precise Robust Inertial Guidance for Munitions (PRIGM) program aims to develop inertial sensor technologies for positioning, navigation, and timing (PNT) in GPS-denied environments. When GPS is not available, these inertial sensors can provide autonomous PNT information. The program will exploit recent advances in integrating photonic (light-manipulating) components into electronics and in employing Microelectromechanical Systems (MEMS) as high-performance inertial sensors for use in extreme environments. Whereas conventional MEMS inertial sensors can suffer from inaccuracies due to factors such as temperature sensitivity, new photonics-based PNT techniques have demonstrated the ability to mitigate these inaccuracies. PRIGM will focus on two areas. By 2020, it aims to develop and transition a Navigation-Grade Inertial Measurement Unit (NGIMU), a state-of-the-art MEMS device, to DoD platforms. By 2030, it aims to develop Advanced Inertial MEMS Sensors (AIMS) that can provide gun-hard, high-bandwidth, high dynamic range navigation for GPS-free munitions. These advances should enable navigation applications, such as smart munitions, that require low-cost, size, weight, and power inertial sensors with high bandwidth, precision, and shock tolerance. PRIGM will advance state-of-the-art MEMS gyros from TRL-3 devices to a TRL-6 transition platform, eventually enabling the Service Labs to perform TRL-7 field demonstrations. Basic research for this program is funded within PE 0601101E, Project ES-01 and advanced technology development for the program is budgeted in PE 0603739E, Project MT-15. ***FY 2019 Plans:*** - Demonstrate 100x increase in frequency stability and 3x reduction in power consumption in MEMS clock oscillators. - Package all component technology and test photonic-MEMS inertial sensor performance, robustness to environmental temperature variation, and repeatability between routine operations. ***FY 2020 Plans:*** - Demonstrate inertial sensor survival and operation through laboratory-representative launch events. ***FY 2019 to FY 2020 Increase/Decrease Statement:***			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*	**Project (Number/Name)** ELT-01 / *ELECTRONIC TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The decrease in FY 2020 reflects completion of design to transition of packaging component technology and testing inertial sensor performance.			
Title: Wafer-scale Infrared Detectors (WIRED) ***Description:*** The WIRED program addresses the need for low-cost, high-performance imaging sensors in the short-wave and mid-wave infrared (SWIR/MWIR) bands. These sensors will provide increased standoff distances for small unmanned aerial vehicles, low-cost missiles, handheld weapon sights and surveillance systems, helmet-mounted systems, and ground-vehicle-mounted threat warning systems. WIRED proposes to manufacture these sensors at the wafer scale, which reduces costs by processing dozens to hundreds of camera imaging arrays at a time. Wafer-scale manufacturing has already driven a revolution in optical imaging in both the visible and the Long-Wave Infrared (LWIR) spectrum, with high-resolution digital cameras and LWIR sensors having become commonplace or widely-available. However, no similar technologies exist for the SWIR/MWIR bands. WIRED could therefore drive a similar revolution in SWIR/MWIR. The program aims to significantly reduce the weight and volume of MWIR detectors, which today require heavy cryogenic cooling systems, and increase the resolution of SWIR detectors by dramatically reducing their pixel size relative to the state-of-the-art. ***FY 2019 Plans:*** - Demonstrate an integrated MWIR camera and evaluate performance at temperature of 270 K. - Demonstrate an integrated small-pitch SWIR camera and optimize design of high-resolution SWIR camera. ***FY 2020 Plans:*** - Demonstrate improved performance of a both the MWIR and SWIR cameras. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects the program transitioning to final demonstrations.	19.000	15.000	7.682
Title: Modular Optical Aperture Building Blocks (MOABB) ***Description:*** The Modular Optical Aperture Building Blocks (MOABB) program aims to greatly improve the cost, size, weight, and performance of free-space optical systems. These systems enable applications such as Light Detection And Ranging (LIDAR), laser communications, laser illumination, navigation, and 3D imaging. Specifically, MOABB will construct millimeter-scale optical building blocks that can be coherently arrayed to form larger, higher power devices. These building blocks would replace the traditional large and expensive precision lenses and mirrors, which require slow mechanical steering, that form conventional optical systems. MOABB will develop scalable optical phased arrays that can steer light waves without the use of mechanical components. These advances would allow for a 100-fold reduction in size and weight and a 1,000-fold increase in the steering rate of optical systems. ***FY 2019 Plans:***	21.000	20.000	20.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Demonstrate frequency modulated LIDAR functionality of a unit cell. - Improve the aperture size, output power, field of regard, and efficiency of optical phased array transmitters. - Co-package optical phased arrays with chip-scale laser sources. ***FY 2020 Plans:*** - Synthesize multiple light beams from a single optical phased array aperture of one square centimeter area. - Demonstrate integration of laser sources and optical phased arrays on a single photonic chip. - Characterize and deliver a prototype LIDAR module using optical phased arrays.			
Title: Atomic Clock with Enhanced Stability (ACES) ***Description:*** The Atomic Clock with Enhanced Stability (ACES) program aims to develop extremely stable chip-scale atomic clocks for unmanned aerial vehicles and other low size, weight, and power (SWaP) platforms with extended mission durations. Atomic clocks provide the high-performance backbone of timing and synchronization for DoD navigation; communications; electronic warfare (EW); and intelligence, surveillance, and reconnaissance (ISR) systems. However, atomic clocks are limited, particularly by temperature sensitivity, aging over long timescales, and a loss of accuracy when power cycled. By employing alternative approaches to confining and measuring atomic particles, ACES could yield a 100x - 1,000x improvement in key performance parameters related to each of these limitations. ACES will also focus on developing the component technologies necessary for low-cost manufacturing and for deployment in harsh DoD-relevant environments. Among its many benefits, program success could help reduce the risk posed by a growing national dependence on GPS, allowing systems to maintain their timing accuracy in the event of temporary GPS unavailability. ***FY 2019 Plans:*** - Complete fabrication and testing of an integrated physics package meeting the ACES Phase 2 SWaP, retrace, aging, and instability goals. - Deliver prototype physics package and supporting electronics to government facility for testing. ***FY 2020 Plans:*** - Design an integrated physics package meeting Phase 3 SWaP objectives such that prototypes can be completed and tested. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects ACES completing fabrication and conducting final testing for transition to the Service Labs for further development.	21.000	16.000	6.000
Title: Limits of Thermal Sensors (LOTS) ***Description:*** The Limits of Thermal Sensors (LOTS) program aims to demonstrate long-wave infrared (LWIR) detector technologies with both high performance and low-size, weight, power, and cost (SWaP-C). The resulting technologies would	9.000	7.668	7.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
enable improvements in imaging systems such as night-vision goggles, infrared-guided missiles, and missile threat warning systems. Currently, LWIR-enabled systems must choose between large and expensive cryogenically-cooled detectors, which offer high sensitivity and low response times, and uncooled detectors called microbolometers, which offer significant SWaP-C reductions at lower performance. LOTS seeks to develop microbolometers that can compete with larger cameras in terms of higher sensitivity required to detect signals over long ranges and lower response time required to avoid image blur. These technologies will allow DoD to deploy smaller, lighter, and cheaper sensors on critical, high-value assets while maintaining or improving their ability to engage fast-moving or distant targets. ***FY 2019 Plans:*** - Build LWIR cameras with refined sensors to meet final program specifications. - Validate test camera sensitivity and response time in a relevant application environment. ***FY 2020 Plans:*** - Validate improved robustness of the test camera in response to relevant radiation conditions. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects the program transitioning from refining sensors to validating test camera hardening performance.			
Title: Atomic Magnetometry for Biological Imaging In Earth's Native Terrain (AMBIIENT)	12.000	11.540	14.000
Description: The Atomic Magnetometry for Biological Imaging In Earth's Native Terrain (AMBIIENT) program will develop novel magnetic sensors capable of providing high-sensitivity signal measurements in the presence of ambient magnetic fields. In recent years, the value of magnetic imaging, for example for cardiac and other biological signals, has shown tremendous potential for advanced research and clinical diagnosis. Practical application, however, has been limited. Interference from natural and manmade ambient magnetic fields has required that the measurements be performed in specialized, magnetically-shielded research facilities. The AMBIIENT program will exploit novel physical architectures that are resistant to the impact of common noise sources. The AMBIIENT sensor itself must be able to detect the gradient of a local magnetic field while subtracting the much larger ambient signal. This would enable low-cost, portable, high-sensitivity measurements for in-the-field applications. In addition to medical research and clinical diagnosis, AMBIIENT sensors promise to enable diverse sensing applications including magnetic gradient navigation, anomaly detection, perimeter monitoring, and Ultralow Frequency (ULF) communications. ***FY 2019 Plans:*** - Fabricate and test preliminary architectures for direct gradient sensing of magnetic fields. - Refine quantitative models of gradient sensor physics.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*	**Project (Number/Name)** ELT-01 / *ELECTRONIC TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Perform laboratory testing of proof-of-principle gradient sensor physics package meeting AMBIIENT Phase 1 size weight and power, accuracy, and sensitivity goals. ***FY 2020 Plans:*** - Design sensor package architecture meeting AMBIIENT Phase 2 size weight and power, accuracy, and sensitivity goals. - Fabricate and test Phase 2 architectures for direct gradient sensing of magnetic fields. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects a shift from initial testing to sensor package architecture fabrication.			
Title: Dynamic Range-enhanced Electronics and Materials (DREaM) ***Description:*** The Dynamic Range-enhanced Electronics and Materials (DREaM) program aims to develop intrinsically linear (ideal) radio frequency (RF) transistors with improved power efficiency and extremely high dynamic range. Linearity, power efficiency, and dynamic range are fundamental characteristics that allow RF systems to reliably transmit clear signals. Improving these characteristics is essential to operating in a crowded RF environment and to enabling next-generation communication, sensing, and electronic warfare systems. Traditional RF transistor designs typically require a trade-off between linearity and broadcast power, and poor linearity results in undesired interference. DREAM will overcome this tradeoff by employing new transistor materials, architectures, and designs. The resulting DREAM-enabled technologies will allow future RF electronics to increase their operating range without polluting the already-congested RF spectrum and while consuming less system power. ***FY 2019 Plans:*** - Develop initial low noise and lower power consumption linear transistor prototype that provides 10 times improvement of linearity figure of merit than the state of the art. - Demonstrate fabrication processes for initial advanced transistor architectures and complete early characterization of RF transistor prototypes with two times improvement in output power over the state of the art. ***FY 2020 Plans:*** - Manufacture and characterize transistor unit cells with both a three times improvement over the state of the art in output power density and 10 times higher linearity. - Optimize fabrication processes and explore novel transistor topology to enable higher breakdown voltage, for design of transistors with four times higher power density than the state of the art. - Exploit new channel materials and perform device modeling to enable scaling to 30 times higher linearity than state of the art at 30 gigahertz operational frequency. ***FY 2019 to FY 2020 Increase/Decrease Statement:***	14.000	15.000	16.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The FY 2020 increase reflects the program transitioning from developing advanced transistor architectures to manufacturing transistor unit cells.			
Title: Wideband Secured and Protected Emitter and Receiver (WiSPER)* ***Description:*** *formerly Ensured Communication Link for Identification Friend or Foe (ECLIFF) The Wideband Secured and Protected Emitter and Receiver (WiSPER) program aims to develop an ultra-broadband technology platform to demonstrate a robust, secure and protected communication link. WiSPER technology provides high signal coding gain to deliver a secured and protected link with significantly enhanced capacity for next generation DoD communications. Current terrestrial tactical radios operate with limited bandwidth at prescribed low frequency bands, which are unable to support high capacity with multiple users, and vulnerable to interference and jamming. WISPER technology addresses military needs for assured communications, electronic warfare (EW) communications deception, throughput, security, and size, weight, and power (SWaP) limitations of future C4ISR missions. The program develops an ultra-broadband compact antenna, radio frequency front end electronics, mixed signal circuits, and featureless waveform technologies. The WiSPER program will culminate with the integration and demonstration of a secured communication link. The WiSPER program moved from ELT-02, Beyond Scaling Technologies, in FY 2019. ***FY 2019 Plans:*** - Complete system study of secured transceiver architecture for ultra-broadband communication links. - Begin initial designs of antenna, integrated circuits, and waveform to implement ultra-broadband communications. ***FY 2020 Plans:*** - Develop and fabricate components of the 1st-generation of transceivers. - Integrate the 1st-generation prototype transceivers. - Demonstrate prototype secured radio link operation in laboratory testing environment. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects the program shifting from initial designs of antenna, and integrated circuits to developing and fabricating components of the 1st-generation of transceivers.	-	6.000	17.000
Title: SHort Range Independent Microrobotic Platforms (SHRIMP) ***Description:*** The SHort Range Independent Microrobotic Platforms (SHRIMP) program will develop and demonstrate multi-functional millimeter-to-centimeter scale robotic platforms with a focus on untethered mobility, maneuverability, and dexterity. To achieve this goal, SHRIMP will also provide foundational research in the area of micro-actuator materials and energy efficient power systems for extremely size, weight, and power (SWaP)-constrained microrobotic systems. The program's platform	-	4.500	12.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
development activities will leverage recent advances in low power, application specific integrated circuit (ASIC) electronics and low power sensors from the internet of things (IoT) community to increase the functionality of microrobotic platforms while increasing platform mobility, maneuverability, and dexterity. The microrobotic platform capabilities enabled by SHRIMP will provide the DoD with significantly more access and capability to operate in small spaces that are practically inaccessible to today's state-of-the-art robotic platforms. Such capability will have impact in search and rescue, disaster relief, infrastructure inspection, and equipment maintenance, among other operations. Foundational research efforts are funded in PE 0601101E, Project ES-01. ***FY 2019 Plans:*** - Initiate development of tethered microrobotic platforms with emphasis on program metrics for size, weight, and duration of operation. ***FY 2020 Plans:*** - Demonstrate tethered microrobotic platforms meeting program metrics on size, weight, and duration of operation. - Initiate development of an untethered microrobotic platform with an emphasis on size, weight, and performance. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects the program shifting from initial development to demonstration of tethered microrobotic platforms.			
Title: Intelligent Spectroscopic & Temporal Fusion (INSPECT) ***Description:*** The Intelligent Spectroscopic & Temporal Fusion (INSPECT) program will add relevant spectral content to broadband infrared (IR) imagers to enhance battlefield detection and discrimination while maintaining situational awareness. The resulting desired capability is analogous to human vision that relies upon shape, brightness, and color to recognize and identify objects of interest. Currently fielded systems are either broadband infrared sensors that rely on shape and brightness to identify targets or hyperspectral sensors that rely on color to identify targets. INSPECT will (1) leverage read-out integrated circuits currently in development combined with advances in electrically tunable optical filters and micro-optical components to demonstrate hardware that simultaneously provides situational awareness and target spectral characteristics, and (2) develop intelligent processing for mission-specific band selection. This will enable new applications in passive seeker technology for missiles, battlefield chemical sensing, laser weapon identification and protection, and low probability of detection multi-spectral optical communications. ***FY 2020 Plans:*** - Develop preliminary architecture for use with existing broadband imaging hardware. - Develop preliminary algorithms that provide intelligent band selection. - Begin initial design integration using INSPECT framework. ***FY 2019 to FY 2020 Increase/Decrease Statement:***	-	-	12.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The FY 2020 increase reflects program initiation.			
Title: Instinctual RF	-	-	11.200
Description: The Instinctual RF program will develop radio frequency (RF) front-end technology that can protect wideband digital radios against external electromagnetic threats and self-interference, through tunable filtering, limiting, or signal cancellation. Today's multi-function phased arrays that cover broad bandwidth are open to all frequencies with little or no RF filtering. This is due to a lack of reconfigurable filtering that is small enough to integrate into the arrays, limiting the use of wideband multi-function arrays in contested environments. The ability to create reconfigurable bandpass and bandstop filters in the range of 2-18 GHz will be important to implementing transmit/receive modules in next generation multi-function arrays. Another important area of interference mitigation is self-interference. Specifically, in electronic warfare, it would be advantageous to be able to listen while jamming. Instinctual RF will develop the signal cancellation devices that will listen to the transmit signal and subtract the interfering signal from the input of the receiver so that it will be able to hear faint signals near the noise floor. Instinctual RF research will provide feedback mechanisms that instinctively correct these problems, much like the nerves of the human body serve to trigger protective action without conscious thought. Whether for self-induced interference or external interference jamming, this program will show the ability to auto-correct and allow for continued operation. ***FY 2020 Plans:*** - Demonstrate new materials, devices and/or circuit architectures that will enable frequency tuning of band pass and band stop filters in chip-scale size for use in next generation multi-function phased arrays. - Demonstrate new materials, devices and/or circuit architectures that will enable cancellation of signal leakage between two adjacent antennas for electronic warfare applications on small platforms. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.			
Title: Direct On-Chip Digital Optical Synthesis (DODOS)	13.000	3.000	-
Description: The Direct On-chip Digital Optical Synthesis (DODOS) program will integrate diverse electronic and photonic components to create a compact, robust, and highly-accurate optical frequency synthesizer for various mission-critical DoD applications. Frequency synthesis and accurate control of radiofrequency and microwave radiation is the enabling technology for radar, satellite and terrestrial communications, positioning and navigation technology, and many other core DoD capabilities. Frequency synthesis and control of light or optical waves, however, has been constrained to laboratory experiments due to the size, fragility, and cost of optical frequency synthesizers. DODOS will leverage recent developments in the field of integrated photonics to enable the development of a ubiquitous, low-cost optical frequency synthesizers. The program could lead to disruptive DoD capabilities, including high-bandwidth optical communications, higher performance Light Detection And Ranging			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
(LiDAR), portable high-accuracy atomic clocks, and high-resolution detection of chemical/biological threats at a distance. Basic research for this program is funded within PE 0601101E, Project ES-01. ***FY 2019 Plans:*** - Demonstrate operation of multiple photonic chips in initial synthesizer prototype. - Characterize and deliver multiple DODOS prototypes comprising co-integrated optical frequency synthesizer and control electronics. - Demonstrate a low-noise microwave frequency synthesizer using DODOS components. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Title: Common Heterogeneous integration & IP reuse Strategies (CHIPS) ***Description:*** The Common Heterogeneous integration & IP reuse Strategies (CHIPS) program aims to develop the design tools and integration standards required to better leverage leading-edge commercial sector technologies in DoD systems. The program aims to realize modular Integrated Circuits (ICs) that integrate designs using different commercial suppliers and silicon technologies. CHIPS will therefore pursue standardized interfaces for integrating a variety of Intellectual Property (IP) blocks in the form of prefabricated chiplets. The chiplets could be reused across applications, manufacturers, and transistor types, allowing DoD to amortize IC design costs across programs, better align electronics design and fabrication with military performance goals, and expand beyond its traditional reliance on the proprietary capabilities of a few on-shore manufacturers. The CHIPS program moves to Project ELT-02, Beyond Scaling Technologies, in FY 2019.	28.250	-	-
Title: Near Zero Energy RF and Sensor Operations (N-ZERO) ***Description:*** The Near Zero Power RF and Sensor Operations (N-ZERO) program will develop and demonstrate the technologies required to extend the lifetimes of remotely-deployed sensors from months to years. Today's state-of-the-art sensors can be pre-placed and remain dormant until awoken by an external trigger or stimulus. However, the active electronics that monitor for external triggers consume power, limiting sensor lifetimes to between weeks and months. N-ZERO seeks to replace these electronics with passive or extremely low-power devices that continuously monitor the environment and wake up active electronics upon detection of a specific trigger. This would eliminate or significantly reduce standby power consumption, ensuring that sensor lifetimes are limited only by the power required to process and communicate confirmed events. In doing so, N-ZERO could enable wireless sensors with drastically increased mission life and help meet DoD's unfulfilled need for a persistent, event-driven sensing capability. N-ZERO's applied research component will focus on developing radio frequency (RF) communications and physical sensor systems that use energy from an external trigger to collect, process, and detect useful information while rejecting spurious signals and noise. The N-ZERO program moves to Project ELT-02, Beyond Scaling Technologies, in FY 2019.	20.000	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*	**Project (Number/Name)** ELT-01 / *ELECTRONIC TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Circuit Realization At Faster Timescales (CRAFT) ***Description:*** The Circuit Realization At Faster Timescales (CRAFT) program will develop novel integrated circuit (IC) design flows to reduce by ten times the design and verification effort required for high-performance military electronics. CRAFT will also reduce barriers to the design and fabrication of custom ICs in leading-edge complementary metal oxide semiconductor (CMOS) technology. When selecting electronics for advanced systems, DoD currently must choose between high-performing custom ICs that take years to design and verify or significantly lower-performing general purpose ICs that can be implemented in a few months. The need to protect sensitive IC information further limits DoD's ability to access certain leading-edge commercial electronics. To reduce the design and verification effort, CRAFT will investigate and leverage novel design flows that utilize recent advances in electronic design automation and software design methodologies. These design flows could reduce the manual labor required to develop and verify custom ICs. CRAFT will also explore increased design reuse and flexibility, which will allow DoD to migrate chip fabrication between different foundries or to more advanced technology nodes. These capabilities can help to ensure that the DoD has multiple potential suppliers for critical ICs and help keep military electronics at the leading edge. The CRAFT program moves to Project ELT-02, Beyond Scaling Technologies, in FY 2019.	24.430	-	-
Title: Beyond Scaling - Materials ***Description:*** The Beyond Scaling - Materials program will demonstrate the integration of novel materials into next-generation logic and memory components. Historically, the DoD had taken the lead in shaping the electronics field through research in semiconductor materials, circuits, and processors. However, as DoD focuses on military-specific components and commercial investments eschew the semiconductor space, U.S. fundamental electronics research is stagnant just as an inflection point in Moore's Law (silicon scaling) is about to occur. This program will pursue potential enhancements in electronics that do not rely on Moore's Law, including research not only into new materials but also into the implications of those materials at the device, algorithm, and packaging levels. Research areas will include heterogeneous integration of multiple materials, "sticky logic" devices that combine elements of computation and memory, and leveraging three-dimensional vertical circuit integration to demonstrate dramatic performance improvements with older silicon technologies. The program aims to demonstrate the manufacturability of functioning switches, memory, and novel computational units in a large-scale system. Previous DARPA work on unconventional computing, integration, and reprogrammable memory give confidence in this approach. Basic research for this program is funded within PE 0601101E, Project ES-02. The Beyond Scaling - Materials program moves to ELT-02, Beyond Scaling Technologies, in FY 2019.	16.000	-	-
Title: Beyond Scaling - Design* ***Description:*** *Formerly part of Beyond Scaling - Architectures and Design	27.000	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*	**Project (Number/Name)** ELT-01 / *ELECTRONIC TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The Beyond Scaling - Design will develop and demonstrate the tools required for rapidly designing and deploying specialized circuits. As Moore's Law slows and the nation loses the benefit of free, exponential improvements in electronics cost, speed, and power derived from silicon scaling, the DoD will need to maximize the benefits of available silicon technologies by using design tools that enable circuit specialization. Research efforts will explore technologies and techniques such as intelligent design tools, automated physical layout generation, open-source circuit designs, and complete hardware emulation prior to manufacturing. Further research will also develop tools to create exact representations of outdated hardware in the field and to rapidly, cheaply, and safely upgrade these systems with next-generation electronics. The goal of this program is to reduce the barrier to entry for complex system-on-chip (SoC) designs and to provide a secure pathway for the rapid upgrade of electronics. Advances under this program will demonstrate a new DoD capability to create specialized hardware and provide electronics improvements that do not depend on continued, rapid silicon scaling. Basic research for this program is funded within PE 0601101E, Project ES-02. The Beyond Scaling - Design program moves to Project ELT-02, Electronic Technology, in FY 2019.			
Title: Beyond Scaling - Architectures* ***Description:*** *Formerly part of Beyond Scaling - Architectures and Design The Beyond Scaling - Architectures program will demonstrate a new DoD capability to create and utilize specialized hardware by enabling the writing of a common code base on top of customized hardware. The program will explore technologies and techniques such as new domain-specific circuit architectures; co-design of electronics hardware and software; intelligent edge sensors; hardware security architectures; and tight integration of chip-scale processing blocks and artificial intelligence-enabled processing controllers. Basic research for this program is funded within PE 0601101E, Project ES-02. The Beyond Scaling - Architectures program moves to Project ELT-02, Electronic Technology, in FY 2019.	22.000	-	-
Accomplishments/Planned Programs Subtotals	283.180	115.208	135.882

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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602716E / *ELECTRONICS TECHNOLOGY*	Project (Number/Name) ELT-02 / *BEYOND SCALING TECHNOLOGY*	

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
ELT-02: *BEYOND SCALING TECHNOLOGY*	-	0.000	233.639	196.310	-	196.310	192.700	203.900	204.210	204.210	-	-

A. Mission Description and Budget Item Justification

The Beyond Scaling Technology project recognizes that, within the next decade, the continuous pace of improvements in electronics performance will face the fundamental limits of silicon technology. These limits present a barrier that must be overcome in order for progress to continue. This project will therefore pursue potential electronics performance advancements that do not rely on Moore's Law but instead leverage circuit specialization, to include materials, architectures, and designs intended to suit a specific need. In addition, the Beyond Scaling Technology Project recognizes that the envisioned electronics specialization will require proper security safeguards. Electronics advancements must simultaneously make progress in performance and secure the foundation on which our digital infrastructure relies. Programs within the Beyond Scaling project will look at reducing barriers to making specialized circuits in today's silicon hardware and significantly increase the ease with which DoD can design, deliver, and eventually upgrade critical, customized electronics. Programs will also explore alternatives to traditional circuit architectures, for instance by exploiting vertical circuit integration to optimize electronic devices and by incorporating novel materials, and explore techniques for securing DoD and commercial data and hardware. This project aggregates and continues Beyond Scaling programs that were initiated in PEs/Projects 0602716E/ELT-01 and 0602303E/ IT-02 and IT-03.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Beyond Scaling - Materials	-	44.349	46.000
Description: The Beyond Scaling - Materials program will demonstrate the integration of novel materials into next-generation logic and memory components. Historically, the DoD had taken the lead in shaping the electronics field through research in semiconductor materials, circuits, and processors. However, as DoD focuses on military-specific components and commercial investments eschew the semiconductor space, U.S. fundamental electronics research is stagnant just as an inflection point in Moore's Law (silicon scaling) is about to occur. This program will pursue potential enhancements in electronics that do not rely on Moore's Law, including research not only into new materials but also into the implications of those materials at the device, algorithm, and packaging levels. Research areas will include heterogeneous integration of multiple materials, "sticky logic" devices that combine elements of computation and memory, and leveraging three-dimensional vertical circuit integration to demonstrate dramatic performance improvements with older silicon technologies. The program aims to demonstrate the manufacturability of functioning switches, memory, and novel computational units in a large-scale system. Previous DARPA work on unconventional computing, integration, and reprogrammable memory give confidence in this approach. Basic research for this program is funded within PE 0601101E, Project ES-02. The Beyond Scaling - Materials program moved from Project ELT-01, Electronic Technology, in FY 2019.			
FY 2019 Plans: - Demonstrate yield of the first complex three dimensional evaluation circuit.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*	**Project (Number/Name)** ELT-02 / *BEYOND SCALING TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Release initial design tools to be used for design of three dimensional monolithic circuits. - Demonstrate enhanced yield from circuits using alternative materials fabricated in a 90nm foundry and the ability to scale to larger circuits. ***FY 2020 Plans:*** - Demonstrate fabrication of fully integrated monolithic 3D circuits at a commercial fabrication facility. - Release distribution quality design tools to enable external design of monolithic three dimensional circuits. - Demonstrate large-scale fully functional chips using alternative materials fabricated in a 90 nm foundry with capabilities that are competitive with advanced technology nodes. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects the program transitioning towards demonstrating the ability to take alternative materials through a full commercial process flow.			
Title: Beyond Scaling - Architectures*	-	43.000	42.000
Description: *Formerly part of Beyond Scaling - Architectures and Design The Beyond Scaling - Architectures program will demonstrate a new DoD capability to create and utilize specialized hardware by enabling the writing of a common code base on top of customized hardware. The program will explore technologies and techniques such as new domain-specific circuit architectures; co-design of electronics hardware and software; intelligent edge sensors; hardware security architectures; and tight integration of chip-scale processing blocks and artificial intelligence-enabled processing controllers. Basic research for this program is funded within PE 0601101E, Project ES-02. The Beyond Scaling - Architectures program moved from Project ELT-01, Electronic Technology, in FY 2019. ***FY 2019 Plans:*** - Demonstrate that a hardware scheduler will allow for the optimal routing on a specialized integrated circuit in situ of operation. - Initiate design of system-on-chips (SOCs) with heterogeneous mix of processors and algorithm accelerators to solve domain-specific compute problems with good power and performance. - Initiate reconfigurable architecture development and diverse data flow management scheme. - Initiate the definition of a software development environment to enable co-design of reconfigurable hardware. ***FY 2020 Plans:*** - Demonstrate ability to emulate a specialized processor capable of efficiently executing two simultaneous applications. - Demonstrate initial reconfigurable architecture simulation and emulation environment that will drive hardware design decisions and definitions.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*	**Project (Number/Name)** ELT-02 / *BEYOND SCALING TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Advance the software tools, development technologies, and design methodologies for SOCs with heterogeneous components that can be easily reprogrammed for specialized applications. - Develop version two of programming languages and compilers that optimize software and hardware at runtime for reconfigurable processors. - Implement an interconnect architecture for a single common embedded bus with the ability to physically isolate high risk transactions and enforce data security and privacy. - Demonstrate 100Mbps sustained throughput across a two-level security architecture and integrate sensitive data isolation techniques into an application relevant to DoD systems. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects minor program repricing.			
Title: Beyond Scaling - Design* ***Description:*** *Formerly part of Beyond Scaling - Architectures and Design The Beyond Scaling - Design will develop and demonstrate the tools required for rapidly designing and deploying specialized circuits. As Moore's Law slows and the nation loses the benefit of free, exponential improvements in electronics cost, speed, and power derived from silicon scaling, the DoD will need to maximize the benefits of available silicon technologies by using design tools that enable circuit specialization. Research efforts will explore technologies and techniques such as intelligent design tools, automated physical layout generation, open-source circuit designs, and complete hardware emulation prior to manufacturing. Further research will also develop tools to create exact representations of outdated hardware in the field and to rapidly, cheaply, and safely upgrade these systems with next-generation electronics. The goal of this program is to reduce the barrier to entry for complex system-on-chip (SoC) designs and to provide a secure pathway for the rapid upgrade of electronics. Advances under this program will demonstrate a new DoD capability to create specialized hardware and provide electronics improvements that do not depend on continued, rapid silicon scaling. Rapid design and deployment techniques developed will also consider the need to incorporate security into DoD hardware. Basic research for this program is funded within PE 0601101E, Project ES-02. The Beyond Scaling - Design program moved from Project ELT-01, Electronic Technology, in FY 2019. ***FY 2019 Plans:*** - Determine standards and requirements for interfacing between multiple software modules that will enable the creation of a unified software platform capable of integrating intelligence and learning. - Release an alpha version of the hardware design platform that demonstrates automation within individual software modules, and complete initial evaluation by program collaborators to identify major bugs. - Complete initial design of mixed signal open source Intellectual Property (IP) and gather feedback on IP from government and program users.	-	33.000	40.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*	**Project (Number/Name)** ELT-02 / *BEYOND SCALING TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Finalize standards required to interface between multiple verification modules and demonstrate initial functionality of verification software against a small set of benchmark mixed signal circuits. ***FY 2020 Plans:*** - Deliver software for physical layout of integrated circuits, packages and boards that is 100% automated and achieves 50% power, performance and area compared to traditional best in class techniques. - Demonstrate fabrication of circuits generated from high-level schematics using a fully automated intelligent design flow. - Publically release open source IP modules developed in the program and demonstrate portability between multiple technology nodes. - Publically release a hardware verification platform with functionality evaluated through simulation and emulation of a comprehensive set of digital and mixed signal circuits - Complete an early software release of an emulation flow capable of emulating a small subsystem. - Create an initial testbed to demonstrate accuracy and performance of digital systems designed through hardware emulation to illustrate the reduction of design time and cost. - Define security levels and metrics and establish on-chip and off-chip security infrastructures based on known chip vulnerabilities. - Identify demonstration platforms and develop interface standards for processors that won't reveal manufacturing vulnerabilities using manufacturing and other techniques to enhance security in a secure design flow. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects the transition from initial design and development to the delivery of functional tools, software, intellectual property, and fabricated hardware.			
Title: Common Heterogeneous integration & IP reuse Strategies (CHIPS) ***Description:*** The Common Heterogeneous integration & IP reuse Strategies (CHIPS) program aims to develop the design tools and integration standards required to better leverage leading-edge commercial sector technologies in DoD systems. The program aims to realize modular Integrated Circuits (ICs) that integrate designs using different commercial suppliers and silicon technologies. CHIPS will therefore pursue standardized interfaces for integrating a variety of Intellectual Property (IP) blocks in the form of prefabricated chiplets. The chiplets could be reused across applications, manufacturers, and transistor types, allowing DoD to amortize IC design costs across programs, better align electronics design and fabrication with military performance goals, and expand beyond its traditional reliance on the proprietary capabilities of a few on-shore manufacturers. The CHIPS program moved from Project ELT-01, Electronic Technology, in FY 2019. ***FY 2019 Plans:*** - Complete module design activities to determine performance and program benefits of new processes enabled by the program.	-	15.500	17.800

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*	**Project (Number/Name)** ELT-02 / *BEYOND SCALING TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Initiate fabrication of approved modules to determine performance and program benefits of new processes enabled by the program. - Continue the study of the system level impact of IP re-use for the optimal use of digital functional blocks. ***FY 2020 Plans:*** - Complete module fabrication and testing to demonstrate functionality of the CHIPS interface and chiplets in representative applications. - Initiate design of upgraded modules to determine performance and program benefits of new processes enabled by the program. - Complete the study of the system level impact of IP re-use for the optimal use of digital functional blocks. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects the program shifting from module design to module fabrication.			
Title: System Security Integrated Through Hardware and firmware (SSITH)	-	22.790	19.000
Description: The System Security Integrated Through Hardware and firmware (SSITH) program seeks to secure DoD and commercial electronic systems against cybersecurity threats by developing novel hardware/firmware security architectures and hardware design methodologies. Current responses to cybersecurity attacks typically consist of developing and deploying software patches to address specific vulnerabilities in a software firewall without addressing potential vulnerabilities in the underlying hardware architecture. To address this challenge, SSITH will drive new research in electronics hardware security and exploit current research in areas such as cryptographic-based computing and hardware verification. Implementation of these advanced ideas has been enabled by the extremely capable semiconductor technology driven by Moore's Law. The program will also investigate flexible hardware architectures that adapt to and limit the impact of new cybersecurity attacks. Finally, SSITH will seek to mitigate the potential negative impact of new security protection architectures on system performance and power usage. Once developed, SSITH capabilities will be applicable to both commercial and military electronic systems. The SSITH program moved from Project IT-03, Information Assurance and Survivability, in FY 2019. ***FY 2019 Plans:*** - Implement new hardware architectures on Field-Programmable Gate Array (FPGA) demonstration platforms that demonstrate scalable, flexible, and robust protection against external attacks on embedded and mobile processing hardware. - Utilize simulation and hardware emulation to confirm the expected improvement in protection of the new hardware architectures relative to current software only protection. - Evaluate SSITH security approaches through independent Red Team attack on the security architectures as implemented on FPGA hardware. ***FY 2020 Plans:***			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*	**Project (Number/Name)** ELT-02 / *BEYOND SCALING TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Implement new hardware architectures on FPGA demonstration platforms that demonstrate scalable, flexible, and robust protection against external attacks on high-performance, out-of-order processing hardware. - Develop distribution-ready design tools to implement SSITH hardware protection methods in new hardware. - Utilize simulation and emulation to evaluate the tradeoffs between security, power, and performance of hardware. - Formalize security metrics and establish a clear distribution mechanism for those metrics. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects the program transitioning from implementing hardware design to testing hardware.			
Title: Hierarchical Identify Verify Exploit (HIVE)	-	17.600	16.510
Description: The Hierarchical Identify Verify Exploit (HIVE) program will pursue new hardware architectures and algorithms for improving the efficiency of graph and sparse data analytics. When developing operationally significant intelligence, human analysts today are forced to reduce the scope of the problems that they can address and the tempo of their analyses due to the limitations of currently deployed hardware. Because of these limitations the amount of information gathered is quickly outstripping the human ability to review, process, fuse, and interpret. To resolve this challenge, HIVE seeks to leverage improvements in computational efficiency to augment the analyst's ability to integrate large streams of data. The program will investigate advances in chip architecture and data analytics algorithms that can allow machines to infer meaning out of data based on the information needs of the warfighter. Program success would therefore enable the warfighter to understand far more of the battlespace in real time. The HIVE program moved from Project IT-02, High Productivity, High Performance Responsive Architectures, in FY 2019. ***FY 2019 Plans:*** - Improve the toolsets based on information gathered from previous testing and deliver a beta version of the software. - Expand the code sets and code set analysis for final detailed power and performance analysis. - Develop initial full architectural design and detailed performance analysis to drive final design decisions. - Demonstrate that HIVE can run DoD problem sets on field programmable gate arrays (FPGAs) which emulate the HIVE chip and measure both power and performance improvements of the proposed architectures. ***FY 2020 Plans:*** - Complete development of the FPGA emulator and porting of government workflows. - Finalize the HIVE chip architecture and deliver design for fabrication. - Complete application programming interface for HIVE runtime environment. ***FY 2019 to FY 2020 Increase/Decrease Statement:***			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*	**Project (Number/Name)** ELT-02 / *BEYOND SCALING TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The FY 2020 decrease is the result of development work on architectural design concluding and focusing on delivering final design for fabrication.			
Title: Digital RF Battlespace Emulator (DRBE)	-	8.000	15.000
Description: The Digital RF Battlespace Emulator (DRBE) program aims to develop a large-scale, interactive, emulated radiofrequency (RF) environment, providing the DoD with much needed capability to cost-effectively evaluate adaptive, intelligent, and spatially distributed next-generation RF systems. Current U.S. test infrastructure is no longer able to successfully exercise RF systems in relevant environments, which should account for hundreds of DoD systems coordinating against hundreds of adversary systems. Due to the critical dependency of nearly all platforms and missions on the RF spectrum and the increasingly advanced RF capabilities of peer adversaries, current infrastructure limitations represent a critical capability gap. Existing test approaches are either: 1) small-scale laboratory tests under well controlled but unrealistic conditions or 2) massive training exercises, which occur at most annually due to the required cost and manpower and do not fully collect necessary data. To overcome these limitations, DRBE will leverage advances in massively multi-core computing hardware and high-bandwidth digital cross connects to emulate realistic RF environments that account for RF platform movement, signal propagation effects and delays, signal interference, and interactions between RF systems. The electronics architecture which supports these goals is beyond anything that exists today, based on the power and latency requirements that this emulation environment demands. DRBE will pursue three technical thrust areas: architecture, massively multi-core computing, and scenario modeling. The resulting test environment should allow plug-and-play connections for hundreds of RF systems in a 100 km battlespace test. Multi-system exercises could then be quickly executed through many different combat scenarios and variations. DRBE should therefore serve to develop CONOPS, inform battle plans, and fine-tune the performance of both individual and large groups of RF systems. ***FY 2019 Plans:*** - Conduct architecture scaling analysis to define a solution supporting hundreds of RF systems. - Demonstrate basic physical building blocks that will be able to handle the immense throughput expected. ***FY 2020 Plans:*** - Complete first-generation DRBE system design. - Emulate first-generation DRBE system performance using non-real-time software. - Begin fabrication of a first-generation DRBE system. - Begin development and testing of second-generation DRBE basic physical building blocks. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects the program shifting from design to beginning fabrication of the DRBE system.			
Title: Circuit Realization At Faster Timescales (CRAFT)	-	9.400	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*	**Project (Number/Name)** ELT-02 / *BEYOND SCALING TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Description: The Circuit Realization At Faster Timescales (CRAFT) program will develop novel integrated circuit (IC) design flows to reduce by ten times the design and verification effort required for high-performance military electronics. CRAFT will also reduce barriers to the design and fabrication of custom ICs in leading-edge complementary metal oxide semiconductor (CMOS) technology. When selecting electronics for advanced systems, DoD currently must choose between high-performing custom ICs that take years to design and verify or significantly lower-performing general purpose ICs that can be implemented in a few months. The need to protect sensitive IC information further limits DoD's ability to access certain leading-edge commercial electronics. To reduce the design and verification effort, CRAFT will investigate and leverage novel design flows that utilize recent advances in electronic design automation and software design methodologies. These design flows could reduce the manual labor required to develop and verify custom ICs. CRAFT will also explore increased design reuse and flexibility, which will allow DoD to migrate chip fabrication between different foundries or to more advanced technology nodes. The CRAFT program moved from Project ELT-01, Electronic Technology, in FY 2019. ***FY 2019 Plans:*** - Complete the fourth multi-project wafer shuttle run utilizing the final CRAFT design flows. - Finalize the design vault to facilitate access to the CRAFT design flow and related IP for DoD use. - Utilize design flow and intellectual property (IP) from CRAFT to complete DoD reference designs. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Title: Near Zero Energy RF and Sensor Operations (N-ZERO)	-	10.000	-
Description: The Near Zero Power RF and Sensor Operations (N-ZERO) program will develop and demonstrate the technologies required to extend the lifetimes of remotely-deployed sensors from months to years. Today's state-of-the-art sensors can be pre-placed and remain dormant until awoken by an external trigger or stimulus. However, the active electronics that monitor for external triggers consume power, limiting sensor lifetimes to between weeks and months. N-ZERO seeks to replace these electronics with passive or extremely low-power devices that continuously monitor the environment and wake up active electronics upon detection of a specific trigger. This would eliminate or significantly reduce standby power consumption, ensuring that sensor lifetimes are limited only by the power required to process and communicate confirmed events. In doing so, N-ZERO could enable wireless sensors with drastically increased mission life and help meet DoD's unfulfilled need for a persistent, event-driven sensing capability. N-ZERO's applied research component will focus on developing radio frequency (RF) communications and physical sensor systems that use energy from an external trigger to collect, process, and detect useful information while rejecting spurious signals and noise. A basic research component is budgeted under PE 0601101E, Project ES-01. The N-ZERO program moved from Project ELT-01, Electronics Technology, in FY 2019.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*	**Project (Number/Name)** ELT-02 / *BEYOND SCALING TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
FY 2019 Plans: - Design, implement and test signal processing to improve the detection and classification capabilities of N-ZERO sensor systems in the presence of significant background interference. - Facilitate transition opportunities for microsystems enabling passive or near zero energy collection, processing and detection of RF communications and physical sensor signatures at reduced signal strength. - Continue the development of near zero power wireless wake-up sensors for health monitoring of high-value machinery for aerospace applications. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Accomplishments/Planned Programs Subtotals	-	203.639	196.310

	FY 2018	FY 2019
Congressional Add: DARPA Electronics Resurgence Initiative	-	30.000
FY 2019 Plans: - Initiate or enhance ongoing efforts to demonstrate electronics that can enforce security and privacy protections for electronics components critical to DoD overmatch capabilities. - Confirm, via emulation and physical demonstration, that DARPA-developed hardware security technologies can improve the protection of hardware architectures and national critical infrastructure. - Complete abstractions for the physical design of cryptographic hardware intellectual property for use in critical DoD applications. - Incorporate techniques for the physical isolation of sensitive data processing transactions into an application associated with an ongoing DoD program.		
Congressional Adds Subtotals	-	30.000

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 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 3: *Advanced Technology Development (ATD)*	**R-1 Program Element (Number/Name)** PE 0603286E / *ADVANCED AEROSPACE SYSTEMS*

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	176.200	302.463	279.741	-	279.741	217.434	228.725	188.316	204.316	-	-
AIR-01: *ADVANCED AEROSPACE SYSTEMS*	-	176.200	302.463	279.741	-	279.741	217.434	228.725	188.316	204.316	-	-

A. Mission Description and Budget Item Justification

The Advanced Aerospace Systems program element, budgeted in the Advanced Technology Budget Activity, is focused on exploiting high pay-off opportunities to provide revolutionary new system capabilities, as opposed to incremental or evolutionary advancements, in order to achieve undeterrable air presence at dramatically reduced costs. Rapid prototyping and experimentation of integrated system concepts, as well as enabling vehicle subsystems will be conducted. Programs will explore new architectural concepts that employ a mix of weapon technologies that achieve lethality through a combination of overwhelming performance and overwhelming numbers rather than through the use of singular and costly high value assets. Studies conducted under this program element include examination and evaluation of emerging aerospace threats, technologies, concepts, use of autonomy to minimize risk, and applications for missiles, munitions, and vehicle systems.

B. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	155.406	277.603	379.341	-	379.341
Current President's Budget	176.200	302.463	279.741	-	279.741
Total Adjustments	20.794	24.860	-99.600	-	-99.600
• Congressional General Reductions	-3.000	-5.140			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	30.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	29.994	0.000			
• SBIR/STTR Transfer	-6.200	0.000			
• TotalOtherAdjustments	-	-	-99.600	-	-99.600

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2018	FY 2019
Project: AIR-01: *ADVANCED AEROSPACE SYSTEMS*		
Congressional Add: *Hypersonics Weapons Programs Development and Transition*	-	30.000
Congressional Add Subtotals for Project: AIR-01	-	30.000
Congressional Add Totals for all Projects	-	30.000

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 3: *Advanced Technology Development (ATD)*	**R-1 Program Element (Number/Name)** PE 0603286E / *ADVANCED AEROSPACE SYSTEMS*

Change Summary Explanation

FY 2018: Increase reflects reprogrammings, offset by Congressional reduction and SBIR/STTR transfer.
FY 2019: Increase reflects Congressional adjustments, including a $20 million above threshold reprogramming for the Tactical Boost Glide program.
FY 2020: Decrease reflects rephasing of several Advanced Aerospace Systems programs.

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Hypersonic Air-breathing Weapon Concept (HAWC)	30.000	14.300	10.000

Description: The Hypersonic Air-breathing Weapon Concept (HAWC) program is a Joint DARPA / Air Force effort that will develop and demonstrate 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. 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 2019 Plans:
- Continue software-in-the-loop testing for the demonstration vehicle.
- Continue hardware-in-the-loop testing for the demonstration vehicle.
- Complete flight certification reviews with the test range.
- Begin full-scale thermal-structural testing.
- Complete flight test planning for the demonstration system.
- Continue procurement of test assets and test support equipment.
- Begin assembly, integration, and test of demonstration vehicle.
- Conduct range safety analysis.
- Conduct mission readiness review.

FY 2020 Plans:
- Complete software-in-the-loop testing for the demonstration vehicle.
- Complete hardware-in-the-loop testing for the demonstration vehicle.
- Conduct first flight.
- Conduct interim flight test data analysis.
- Complete flight tests.
- Conduct final flight data review.
- Conduct final program reviews.

FY 2019 to FY 2020 Increase/Decrease Statement:

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
The FY 2020 decrease reflects the completion of vehicle fabrication and initial testing and transition to final flight testing.			
Title: Tactical Boost Glide	68.126	147.000	162.000
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, compatibility, and integration 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 2019 Plans:*** - Continue procurement of hardware for demonstration vehicles. - Complete Assembly, Integration, and Test (AI&T) of Static Test Article (STA). - Complete aeroshell thermo-structural testing. - Continue risk reduction and qualification testing. - Complete test readiness review (TRR) for first flight. - Continue AI&T of remaining test articles. - Continue detailed flight test and range safety planning, coordination, and documentation. - Update Technology Maturity Plans (TMPs) and Risk Management Plans (RMPs). - Plan and conduct additional aerodynamic and aero-thermodynamic risk reduction testing. - Plan and conduct additional material and thermo-structural risk reduction testing. - Plan and conduct additional materials arc-jet testing. - Update aerodynamic and materials databases based on risk reduction test analysis. - Plan additional flight tests for expanded risk reduction. - Procure hardware for additional tests and begin AI&T of test articles. - Implement acquisition approach for second TBG performer to evolve an All-Up Round (AUR) design to a critical design level of maturity. - Plan and conduct second TBG performer aerodynamic and aero-thermodynamic risk reduction testing, including air vehicle and all-up round (AUR) subsonic, transonic, and hypersonic performance and control tests.			

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Plan and conduct second TBG performer material and thermo-structural risk reduction testing, including seals characterization, and engineering environmental and static loads testing. - Update second TBG performer aerodynamics and materials databases based on risk reduction test analysis. - Conduct second TBG performer demonstration system solid rocket motor static fire test. - Develop preliminary requirements for a Navy variant AUR. - Conduct trade studies and assess booster and Vertical Launch System (VLS) integration development needs for a Navy variant AUR. - Begin Navy variant test planning. - Plan and conduct Navy variant risk reduction testing. - Conduct Navy variant AUR Conceptual Design Review. ***FY 2020 Plans:*** - Complete AI&T of Engineering Development Unit (EDU) and two flight test vehicles. - Conduct TRRs for two flights, conduct flight tests, and complete post-flight analysis. - Continue AI&T and conduct TRR of third flight test vehicle. - Continue additional aerodynamic and aero-thermodynamic risk reduction testing. - Continue additional material and thermo-structural risk reduction testing. - Continue additional materials arc-jet testing. - Continue detailed planning of additional flight tests for expanded risk reduction. - Continue procurement of hardware for additional tests and continue AI&T of test articles. - Complete second TBG performer's engineering component testing and design verification testing. - Continue second TBG performer's material and thermo-structural risk reduction testing, including carbon-carbon model validation structural test, and full-scale hot structure test. - Complete fabrication and integration and begin test of second TBG performer's inert operating missiles including ground testing and captive carriage testing. - Complete second performer's subsystem and system-level critical design reviews. - Continue Navy variant risk reduction testing. - Continue detailed Navy variant test planning. - Conduct Navy variant demonstration article Preliminary Design Review(s). ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects additional funds for increased risk reduction, Navy variant development, and second performer.			
Title: Advanced Full Range Engine (AFRE)	35.000	51.288	40.741

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
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. The anticipated transition partner for this effort is the Air Force. ***FY 2019 Plans:*** - Complete manufacturing of full scale combustor and prepare for ground test. - Complete manufacturing and ground demonstrate full scale turbine/common nozzle with water injection. - Complete manufacturing and test of common inlet aerodynamic model. - Complete integrated system (TBCC) design (preliminary and critical design). - Complete manufacturing of full-scale common inlet. ***FY 2020 Plans:*** - Complete full-scale combustor (DMRJ) ground test demonstration. - Complete full-scale inlet test. - Complete component (inlet, combustor, turbine, and nozzle) post-test inspection and refurbishment. - Complete integrated TBCC system assembly, installation and initiate ground test. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects completion of design and fabrication and transition to testing.			
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 and 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 prototype development 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.	3.000	3.000	3.000

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
FY 2019 Plans: - Perform ground and flight experiments to characterize boundary layer transition physics. - Initiate studies of novel concepts. - Perform technology risk assessments to identify critical enabling technologies. ***FY 2020 Plans:*** - Conduct proof-of-concept demonstrations to verify technology feasibility. - Perform initial development of novel aircraft configurations.			
Title: Operational Fires	-	40.000	50.000
Description: The goal of the Operational Fires (OpFires) program is to develop and demonstrate a novel ground-launched system enabling advanced tactical weapons to penetrate modern enemy air defenses and rapidly and precisely engage critical time sensitive targets. This program seeks to develop an advanced booster capable of delivering a variety of payloads at a variety of ranges. Additional considerations include the need for compatible mobile ground launch platforms enabling integration with existing ground forces and infrastructure, and specific system attributes required for rapid deployment and redeployment. The OpFires program will conduct a series of subsystem tests designed to evaluate component design and system compatibility, and culminate in integrated end-to-end flight tests. OpFires will leverage and integrate ongoing investments in hypersonics to achieve these objectives. The transition partner is the Army. In FY18, this program was funded from PE 0602702E, Project TT-04. ***FY 2019 Plans:*** - Complete ground launch platform Systems Requirements Review (SRR) and Conceptual Design Review (CoDR). - Complete booster propulsion system Preliminary Design Review (PDR). - Conduct early propulsion system risk reduction testing. - Complete payload trade studies. - Begin Operational Fires integrated system trade studies. - Complete military utility assessment and wargames. - Begin development of technology maturation plans and risk management plans (TMPs and RMPs). - Begin flight test and range safety planning, coordination, and documentation. ***FY 2020 Plans:*** - Complete propulsion system Critical Design Review (CDR). - Complete integrated weapon System Requirements Review (SRR). - Perform extinguishable propellant formulation and characterization testing (strand tests, 12" motor). - Evaluate combustion stability in 1000 lb hybrid motor. - Develop integrated weapon system technology maturation plan and initial flight test plan.			

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Complete Operational Fires integrated system trade studies. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY2020 increase reflects completion of integrated trade studies and initiation of propellant formulation and testing.			
Title: Air-Ground Autonomous VEhicles (AGAVE) ***Description:*** The Air-Ground Autonomous VEhicles (AGAVE) program will explore the seams between air and ground vehicles. New approaches are required to address one of the most symmetric of all warfighting domains-ground combat. The program will seek to provide improved mobility solutions for supporting combat operations that place unmanned assets forward to explore and inform troops prior to entering an area, or to provide continued perimeter and overhead surveillance during operations. Technologies will be explored to allow increased levels of autonomy, improved operating ranges, improved mobility through complex 3-dimensional battlespaces, and integration of the requirements for both ground and air mobility in complex urban warfare settings. Reduced manning requirements will be a part of the design space evaluation, with unmanned vehicles operating in a supporting role instead of a traditional supported role. Novel approaches to launch and recovery that reduce the need for highly trained personnel dedicated to monitoring unmanned vehicles will be explored. Problems that cross all domains, such as high energy density power supplies, navigation through uncertain and changing environments, and supervisory autonomy of vehicles will be addressed. Novel networking approaches will also be explored to close the seams between ground and air unmanned vehicles and to improve confidence in identifying risks associated with both natural hazards and enemy actions prior to ground personnel entering an area. Cueing from other assets and long range, long duration autonomous assets will be included in the overall tradespace explored. ***FY 2020 Plans:*** - Refine design space and develop system requirements. - Initiate studies in the areas of autonomy, mobility, and energy to define technology development areas. - Develop concepts of operations and system architecture. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.	-	-	14.000
Title: Aircraft and Vehicle IntegrAted Team (AVIATE) ***Description:*** The Aircraft and Vehicle IntegrAted Team (AVIATE) program will study use of an Unmanned Aerial System (UAS) that is an integrated subsystem of a ground vehicle with features to autonomously land, attach, stow, detach, and take-off from its parent ground vehicle while it is on the move to enable on-demand capabilities and drastically improved protection. Ground vehicles could perform traditional UAS missions such as intelligence, surveillance and reconnaissance (ISR) and fires support, as well as unique missions such as electronic attack, sensor emplacement, infrastructure attack, and active protection without having	-	5.875	-

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
to rely on brigade and theater level assets. This effort will explore design interfaces between the air and ground vehicle, attributes to allow for launch and recovery on the move, and design considerations to enable operations in contested environments. ***FY 2019 Plans:*** - Explore airframe design concepts of flight demonstration vehicle. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects completion of studies and concepts.			
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 2019 Plans:*** - Complete integration of the full suite of CODE algorithms and Units of Portability (UoPs). - Demonstrate the ability of a single commander to plan and execute a complex end-to-end scenario. - Perform capstone demonstration involving six live and multiple virtual aircraft executing a complex end-to-end mission scenario with multiple contingency events and limited advanced knowledge of red team positions and tactics. - Complete independent, fully-informed modeling, simulation, and analysis effort to validate final CODE software builds. - Produce final CODE software package with complete software development kit and simulation environment to facilitate technology transfer. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.	30.074	11.000	-
Title: Vertical Take-Off and Landing (VTOL) Technology Demonstrator ***Description:*** The Vertical Take-Off and Landing (VTOL) Technology Demonstrator program sought to demonstrate revolutionary improvements in (heavier than air) VTOL air vehicle capabilities and efficiencies through the development of subsystem and	5.000	-	-

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
component technologies, aircraft configurations and system integration. A strong emphasis was placed on the development of elegant, multi-functional subsystem technologies that demonstrated net improvements in aircraft efficiencies enabling new and vastly improved operational capabilities.			
Title: Tactically Exploited Reconnaissance Node (TERN) ***Description:*** The Tactically Exploited Reconnaissance Node (TERN) program, a joint effort with the Office of Naval Research, developed a systems approach for, and perform technical demonstration of, a Medium-Altitude, Long-Endurance Unmanned Aerial Vehicle (MALE UAV) capability from smaller ships. The program developed 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. TERN enabled novel operational concepts including maritime surveillance and responsive, persistent deep overland ISR and strike, without requirement for forward basing. Application of TERN technologies and operational concepts enabled a novel and cost efficient approach for multiple mission sets. DARPA transitioned the TERN program to the Office of Naval Research for continued development in Q4 FY 2018.	5.000	-	-
Accomplishments/Planned Programs Subtotals	176.200	272.463	279.741

	FY 2018	FY 2019
Congressional Add: Hypersonics Weapons Programs Development and Transition	-	30.000
FY 2019 Plans: - TBG: Conduct risk reduction efforts on additional leading edge materials and additional coating systems. - TBG: Conduct instrumentation development for the leading edge. - TBG: Fabricate and test additional aeroshell. - HAWC: Perform risk reduction efforts and initiate ground testing of the demonstration system. - HAWC: Conduct additional inlet cover ejection test. - HAWC: Complete additional high temperature instrumentation.		
Congressional Adds Subtotals	-	30.000

D. Other Program Funding Summary ($ in Millions)

N/A

Remarks

E. Acquisition Strategy

N/A

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F. Performance Metrics

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

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COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	226.988	254.671	202.606	-	202.606	168.926	142.726	131.726	137.726	-	-
SPC-01: *SPACE PROGRAMS AND TECHNOLOGY*	-	226.988	254.671	202.606	-	202.606	168.926	142.726	131.726	137.726	-	-

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. This program element will examine concepts and architectures that move the U.S. away from a dependence on monolithic, ultra-capable, vulnerable, and unsustainably costly assets; replacing them with disaggregated assets that are agile, affordable, and easily replaced/maintained. Ready access to space requires the delivery of capabilities, replenishment of supplies into orbit, and rapid manufacturing of affordable space capabilities. Development of smaller, simpler, and more agile launch vehicles and infrastructure will be pursued. In addition, developing space access and spacecraft servicing technologies as well as exploring novel in-space manufacturing technologies and techniques 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 and functionality of space systems, space-derived information, and services with terrestrial users. Studies under this program element include technologies and systems that will enable satellites and microsatellites to operate more effectively by increasing maneuverability, survivability, and situational awareness, and precision control of multi-payload systems. Studies will actively seek to take advantage of new commercial developments which may enable both rapid constitution/reconstitution of assets, and agility/functionality not previously available for military systems.

B. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	247.435	254.671	190.606	-	190.606
Current President's Budget	226.988	254.671	202.606	-	202.606
Total Adjustments	-20.447	0.000	12.000	-	12.000
• Congressional General Reductions	-7.000	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	-4.307	0.000			
• SBIR/STTR Transfer	-9.140	0.000			
• TotalOtherAdjustments	-	-	12.000	-	12.000

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Change Summary Explanation

FY 2018: Decrease reflects Congressional reduction, SBIR/STTR transfer and reprogrammings.

FY 2019: N/A

FY 2020: Increase reflects initiation of the Reactor On A Rocket (ROAR) program and funding for DARPA Launch Challenge prize awards, offset by smaller program decreases.

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Experimental Spaceplane One (XSP)	61.000	59.971	51.000

Description: The goal of the Experimental Spaceplane One (XSP) program is to develop and flight demonstrate a prototype booster and expendable upper stage with responsive aircraft-like operations. Past efforts have identified and demonstrated critical enabling technologies including composite or lightweight 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 booster flights in 10 days, 2) design the objective system for >3000-lb payload at a reduced cost, 3) fly the demonstration system one time with an orbital payload of 900-lbs, and 4) fly to a high staging speed (Mach 3-10). The anticipated transition partners are the Air Force, Navy and commercial sector.

FY 2019 Plans:

- Mature the XSP concept through tailored Critical Design Review including complete configuration, aerodynamics and aeroheating, six degree of freedom trajectory calculations with flight software in the loop, mass properties and associated ground systems.
- Conduct Critical Design Review to approve XSP vehicle design for component acquisition, fabrication, assembly, and integration.
- Complete designs for mobile ground infrastructure.
- Mature range, ground and flight test operations planning.
- Submit commercial spaceport and/or DoD range documentation.
- Begin fabrication of all major subsystems.
- Initiate acceptance test planning.
- Begin integration and test of major subassemblies, flight and mobile ground systems.

FY 2020 Plans:

- Complete propulsion qualification and acceptance testing.
- Continue booster assembly integrating actuation devices and control surfaces, landing gear, reaction control system, main engine, and propulsion system hardware.
- Complete Flight Operations Control Center for mobile ground system.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Complete Transporter Erector Launcher system. - Complete the construction of the Liquid Hydrogen (LH2) tank. - Complete nose landing gear assembly. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects completion of fabrication and assembly.			
Title: Robotic Servicing of Geosynchronous Satellites (RSGS)	79.988	108.700	64.606
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 Geosynchronous Satellites (RSGS) program seeks to establish the capability to provide robotic services in GEO suitable for a variety of potential servicing tasks, in full collaboration and cooperation with existing satellite owners and national security space operators, 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. To support the development of a broadly accepted satellite servicing capability, DARPA is using the consortium for execution of rendezvous and servicing operations (CONFERS) approach to bring together experts from the private sector and Government to develop and publish non-binding, consensus-based standards for safe operational approaches. ***FY 2019 Plans:*** - Complete build and test of first flight robotic arm and tool changer. - Begin integration of robotic payload. - Fabricate robotic operations test bed. - Continue build of flight units of robotic tools and tool holders. - Continue preparations for launch with Air Force Space Test Program. - Continue build of rendezvous and proximity operations sensors. - Complete payload structures fabrication. - Test final build of flight software. - Publish CONFERS operating practices document and consensus standards through a qualified standards development organization. - Convene CONFERS second general assembly and open forum. ***FY 2020 Plans:***			

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Complete build and test of second robotic arm and tool changer. - Continue build of flight units of robotic tools and tool holders. - Complete integration of robotic payload. - Test integrated robotic payload. - Begin payload integration on spacecraft. - Complete build of rendezvous and proximity operations sensors. - Test robotic tools and integrate onto spacecraft. - Complete flight software for integration. - Publish revised CONFERS consensus standards inclusive of lessons learned from on-going commercial and government activity. - Convene CONFERS third general assembly and open forum. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects completion of fabrication and integration of payload, tools, and sensors.			
Title: Blackjack	6.000	16.400	25.000
Description: The Blackjack program will develop space technologies demonstrating a proliferated smallsat constellation capability in Low Earth Orbit (LEO). Capabilities demonstrated will provide constant custody of very large numbers of concurrent targets; target identification, tracking, and characterization; architectural resilience via massive proliferation; and rapid on-orbit technology refresh and experimentation. Blackjack will leverage commercial industry plans to build constellations in LEO to provide global commercial broadband internet service. Key efforts include low size, weight, power, and cost (SWaP-C) multi-modality smallsat sensor payloads, algorithms for autonomous payload and architecture command and control, algorithms for satellite on-board processing and data fusion, and advanced manufacturing for military payload mass production. The anticipated transition partner is the Air Force. ***FY 2019 Plans:*** - Complete satellite bus and payload interface definition documents. - Complete demonstration system Conceptual Design Review (CoDR). - Complete Preliminary Design Review (PDR) for modeling and simulation activities. - Begin development of demonstration sensor payloads. - Begin modeling and simulation with bus, payload, and autonomy element emulators for risk reduction efforts. - Begin development of autonomous control element. ***FY 2020 Plans:*** - Complete Critical Design Review for commoditized satellite bus.			

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Complete Critical Design Review for sensor payloads. - Complete Critical Design Review for autonomous control element. - Initiate spacecraft bus manufacturing. - Initiate sensor payload manufacturing. - Initiate autonomous control element manufacturing. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects transition from preliminary to critical design and start of component manufacturing.			
Title: Advanced Space Technology Concepts ***Description:*** Studies conducted under this program will examine and evaluate emerging technologies and concepts with the potential to provide substantial improvement in efficiency and effectiveness of operations in space. This includes the degree and scope of potential impact and improvements to military operations, mission utility, and warfighter capability. Studies are also conducted to analyze emerging 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 advanced or novel propulsion systems, novel sensors, advanced lightweight structures, advanced miniature radio frequency (RF) technology, navigation technologies, avionics, structures, advanced communications and on-orbit software environments. ***FY 2019 Plans:*** - Perform studies to evaluate employment of new systems and architectures. - Explore approaches for autonomous operation of spacecraft architectures. ***FY 2020 Plans:*** - Conduct feasibility studies for new system concepts. - Examine technology developments supporting small space propulsion systems. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects additional planned studies.	3.000	2.000	3.500
Title: Planar Imager ***Description:*** The Planar Imager program will develop a low size, weight, and power (SWaP) electro-optical (EO) imager using photonic integrated circuits (PICs) and other novel approaches to replace conventional telescopes for high altitude, long endurance Unmanned Aerial Vehicle (UAV) persistent platforms and space-based EO sensors for Intelligence, Surveillance, and Reconnaissance (ISR). In order to increase resolution, conventional telescopes have to grow in size and weight. The Planar	-	10.000	10.000

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Imager program will eliminate this constraint by developing methods and technologies to replace conventional optics with digital processing, providing dramatic improvements in weight and enabling novel form factors for military imaging systems. ***FY 2019 Plans:*** - Initiate trade studies of various advanced optics approaches to Planar Imaging (PICs, Metamaterials, etc.). - Develop concept demonstrations requirements. - Initiate breadboard demonstration. ***FY 2020 Plans:*** - Demonstrate breadboard system. - Develop scaled demonstration.			
Title: DARPA Launch Challenge* ***Description:*** *Previously Responsive Access for Space Resilience Advances in technology, including networking and computing, have significantly increased the utility of small (<300kg) spacecraft that would previously have been of limited military value. For the simultaneous purposes of responsiveness and resiliency, these spacecraft are envisioned to be built on dramatically faster timelines (weeks instead of years) than are executed today. The current practice for space launch generally favors large launch vehicles with complex, one-of-a-kind infrastructure. This architecture has been matched to the large, heavy spacecraft, which compose most of DoD's space architecture today. Small spacecraft, which offer large potential value for resiliency and tactical employment, are typically required to rideshare for access to space which requires programmatic, technical, and schedule entanglement with other programs. The U.S. commercial sector has promising developments for small launch vehicles that are designed for launch on rapid timescales with minimal fixed infrastructure. To incentivize industry to deliver capability that can meet emerging DoD needs for rapid, responsive launch of small payloads, the DARPA Launch Challenge will reward competitors who can demonstrate the ability to launch a payload to orbit with minimal notification time and unknown pre-conditions regarding the payload configuration, required orbit, and launch site. The U.S. Government can make future use of commercial contracting mechanisms for rapid space launch with successful performers. The anticipated transition partners are the Air Force and NASA. ***FY 2019 Plans:*** - Select launch ranges and initiate launch site facility accommodations, as necessary. - Develop and test multi-launch site compatible downrange telemetry return capabilities. - Create scalable commercial payload packages to support range of launch capabilities. - Coordinate with the FAA's Office of Commercial Space Transportation on license applications for challenge participants.	-	5.000	38.500

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Review participant challenge applications, to include operations plans demonstrating use of minimal infrastructure, and rapid launch capability. - Select challenge participants for the qualification phase and award qualification prizes. ***FY 2020 Plans:*** - Conduct first and second launches at specified ranges to demonstrate rapid timescale and flexibility. - Award challenge prizes for the first and second launches. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects execution of launch events and prize payments.			
Title: Reactor On A Rocket (ROAR) ***Description:*** The Reactor On A Rocket (ROAR) program will develop and demonstrate a High-Assay Low-Enriched Uranium (HALEU) nuclear thermal propulsion (NTP) system. The capability afforded by NTP will expand the operating presence of the U.S. in space to the cislunar volume and enhance domestic operations to a new high-ground, which is in danger of being defined by the adversary. The program will initially develop the use of additive manufacturing (AM) approaches to print NTP fuel elements. In addition, the program will investigate on-orbit assembly techniques to safely assemble the individual core element subassemblies into a full demonstration system configuration, and will perform a technology demonstration. ***FY 2020 Plans:*** - Demonstrate additive manufacturing techniques using surrogate materials, followed by proof-of-principle additive manufacturing of natural uranium reactor components. - Initiate development of a modular nuclear propulsion system, including incorporation of additively manufactured fuel into a low-enriched uranium reactor and additive engine. - Complete preliminary design of the demonstration integrated nuclear propulsion system. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.	-	-	10.000
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 satellite systems. These satellite systems are expected to have long operational lifetimes, which can leave them behind the pace of state-of-the-	58.000	42.600	-

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
art technical developments. The technologies developed under Radar Net will enable small, low-cost sensor payloads on short timescales with rapid technology refresh capabilities. ***FY 2019 Plans:*** - Transition program to partner for launch and on-orbit demonstration/testing. - Complete final coordination with transition partner on fabrication, assembly, integration, and test of the demonstration system. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
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 support 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 timely sensor tasking. The program will also improve the ability to protect against threats by using modeling and simulation tools to develop courses of action for both natural events and adversary actions. The program will employ artificial intelligence (AI) and machine learning (ML) technologies to increase commander and operator awareness thereby transforming information to knowledge and effectively communicating and facilitating time-critical decision making. Underpinning the BMC2 layer is a flexible infrastructure that enables the rapid integration of tools in order to respond to shifting adversary Tactics, Techniques, and Procedures (TTPs). The anticipated transition partner is the Air Force. ***FY 2019 Plans:*** - Release Hallmark software development kit including Hallmark in-a-box for remote development environment. - Augment the BMC2 tool suite with new technologies that AI and ML to counter complex adversary activities and produce alternative courses of action. - Transition activity for sustainment of ontology and data model continuous evolution, and for sustainment of BMC2 tool development environment. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion and transition.	19.000	10.000	-
Accomplishments/Planned Programs Subtotals	226.988	254.671	202.606

D. Other Program Funding Summary ($ in Millions)

N/A

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide I* BA 3: *Advanced Technology Development (ATD)*	**R-1 Program Element (Number/Name)** PE 0603287E *I SPACE PROGRAMS AND TECHNOLOGY*

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-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 3: *Advanced Technology Development (ATD)*	**R-1 Program Element (Number/Name)** PE 0603739E / *ADVANCED ELECTRONICS TECHNOLOGIES*

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	73.673	111.099	128.616	-	128.616	196.405	220.893	206.678	218.629	-	-
MT-15: *MIXED TECHNOLOGY INTEGRATION*	-	73.673	67.838	58.279	-	58.279	123.405	153.993	154.678	166.629	-	-
MT-16: *BEYOND SCALING ADVANCED TECHNOLOGIES*	-	0.000	43.261	70.337	-	70.337	73.000	66.900	52.000	52.000	-	-

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, integrated photonic-electronic components 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 Mixed Technology Integration project funds the advanced development and demonstration of selected basic and applied electronics research programs. Examples of technologies with funded development and demonstration activities include, but are not limited to: (1) self-contained laser weapon systems to protect airborne platforms from emerging surface-to-air missiles; (2) integrated photonic-electronic components for positioning, navigation and timing in GPS-denied environments; (3) flexible, software-defined cameras that enable real-time image analysis of complex scenes to provide more actionable information; and (4) component programs that integrate mixed signal (analog and digital) or mixed semiconductor technology to substantially improve the capability of existing components and/or reduce their size, weight and power. Funding under this project is intended to advance transitioning novel technologies to use, providing advanced components compatible with mid-term and other future warfighting requirements.

The Beyond Scaling Advanced Technologies project is a continuation of DARPA's basic and applied research in this area and will support activities in large scale co-development with leading industry players to enable and accelerate transformative computing interactions with industry. Additionally, funding under this project will include establishing access to commercial state-of-the-art (SOTA) and state-of-the-practice (SOTP) foundries for DoD microelectronics fabrication runs, developing a manufacturable photonics and wide bandgap process, creating a microelectromechanical systems (MEMS) multi-project wafer flow, and establishing an application center to capture DoD microelectronics requirements.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide I* BA 3: *Advanced Technology Development (ATD)*	**R-1 Program Element (Number/Name)** PE 0603739E *I ADVANCED ELECTRONICS TECHNOLOGIES*

B. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	79.173	111.099	145.159	-	145.159
Current President's Budget	73.673	111.099	128.616	-	128.616
Total Adjustments	-5.500	0.000	-16.543	-	-16.543
• 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	-5.500	0.000			
• TotalOtherAdjustments	-	-	-16.543	-	-16.543

Change Summary Explanation

FY 2018: Decrease reflects SBIR/STTR transfer.

FY 2019: N/A

FY 2020: Decrease reflects rephasing of several Mixed Technology Integration programs.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
MT-15: *MIXED TECHNOLOGY INTEGRATION*	-	73.673	67.838	58.279	-	58.279	123.405	153.993	154.678	166.629	-	-

A. Mission Description and Budget Item Justification

The Mixed Technology Integration project funds the advanced development and demonstration of selected basic and applied electronics research programs. Examples of technologies with funded development and demonstration activities include, but are not limited to: (1) self-contained laser weapon systems to protect airborne platforms from emerging surface-to-air missiles; (2) integrated photonic-electronic components for positioning, navigation and timing in GPS-denied environments; (3) flexible, software-defined cameras that enable real-time image analysis of complex scenes to provide more actionable information; and (4) component programs that integrate mixed signal (analog and digital) or mixed semiconductor technology to substantially improve the capability of existing components and/or reduce their size, weight and power. Funding under this project is intended to advance transitioning novel technologies to use, providing advanced components compatible with mid-term and other future warfighting requirements.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Precise Robust Inertial Guidance for Munitions (PRIGM)	20.500	16.600	8.000
Description: The Precise Robust Inertial Guidance for Munitions (PRIGM) program aims to develop inertial sensor technologies for positioning, navigation, and timing (PNT) in GPS-denied environments. These inertial sensors can provide autonomous PNT information when GPS is unavailable. The program will exploit recent advances in integrating photonic (light-manipulating) components into electronics and in employing microelectromechanical systems (MEMS) as high-performance inertial sensors for use in extreme environments. Whereas conventional MEMS inertial sensors suffer from inaccuracies due to factors such as temperature sensitivity, photonics-based PNT techniques have demonstrated the ability to mitigate these inaccuracies. PRIGM will focus on two areas: (1) By 2020, it aims to develop and transition a Navigation-Grade Inertial Measurement Unit (NGIMU), a state-of-the-art MEMS device, to DoD platforms; and (2) By 2030, it aims to develop Advanced Inertial MEMS Sensors (AIMS) that can provide gun-hard, high-bandwidth, high dynamic range navigation for GPS-free munitions. These advances should enable navigation applications, such as smart munitions, that require low-cost, size, weight, and power (SWaP) inertial sensors with high bandwidth, precision and shock tolerance. PRIGM will advance state-of-the-art MEMS gyros from TRL-3 devices to a TRL-6 transition platform, eventually enabling the Service Laboratories to perform TRL-7 field demonstrations. The ultimate goal is to develop a complete MEMS-based NGIMU with a mechanical/electronic interface identical to existing DoD-standard tactical-grade MEMS IMUs, providing a drop-in replacement for existing DoD systems. Service laboratories have been actively involved throughout program development and remain engaged to facilitate transition of NGIMU prototypes, which will be delivered at the program conclusion. 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 2019 Plans:			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Deliver two MEMS-based, navigation-grade, integrated IMU prototypes for government evaluation. - Commence development of MEMS-based, navigation-grade, integrated IMU meeting program-defined SWaP, performance metrics, environmental requirements, and shock survival. ***FY 2020 Plans:*** - Deliver ten MEMS-based, navigation-grade, integrated IMU prototypes for government evaluation. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects a transition from development to completion and characterization of IMU prototypes.			
Title: Reconfigurable Imaging (ReImagine) ***Description:*** The Reconfigurable Imaging (ReImagine) program aims to create multi-functional readout integrated circuits (ROICs) that fundamentally change the way camera systems collect, process and relay image information. This is accomplished by adding multifunctional flexibility in the ROIC. Today, most cameras are designed to capture high quality imagery at standard frame rates. These traditional camera architectures collect a single type of data across the full image frame. Specialty cameras can be used to capture different spatial, spectral or temporal data but are rarely deployed because of the cost and complexity of adding imaging subsystems for niche measurements. Although these measurements are typically only desired for specific features or regions of interest (ROIs) in a scene, the cameras collect the specialized data over the full image frame. The ReImagine architecture, conversely, would enable a single, real-time reconfigurable, software-defined camera system with the ability to collect different data in different ROIs. Depending on the need, a ReImagine imager would be able to selectively collect and simultaneously process data from a specific ROI, for example, at a higher resolution (i.e., foveated imaging), at a higher frame rate or with 3-D depth information. The system would interface with virtually any sensor and could therefore be used in any spectral band. By demonstrating more efficient data collection and computation across ROIs, ReImagine ROICs should enable real-time analysis of much more complex scenes and provide more actionable information than has ever been possible. Technologies from this program are intended for transition to the Air Force, Navy and Army. ***FY 2019 Plans:*** - Begin the fabrication of a Gen-1 prototype camera integrating the Gen-1 ROIC. - Develop a detailed operational description and simulation for the ReImagine Gen-2 multi-functional digital ROIC, mapping applications and demonstrating enhanced operation and capability. - Initiate design and layout of the ROIC interface and focal plane array layers to operate with the Gen-2 multi-functional digital ROIC for enhanced programmable functionality. - Develop a detailed plan for a Gen-2 multi-functional digital ROIC camera prototype.	23.173	27.738	21.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Complete the design of the ReImagine Gen-2 reconfigurable ROIC, updated and augmented based on Gen-1 performance and experience, and release the design for fabrication. ***FY 2020 Plans:*** - Demonstrate the ReImagine imaging system using the Gen-1 reconfigurable ROIC, fully demonstrating ReImagine reconfigurable sensing system concept. - Complete the ReImagine multi-functional digital ROIC camera prototype system design integrating multiple tier 3D implementation and Gen-2 reconfigurable ROIC. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects a shift from development of a multi-functional digital ROIC camera prototype to conducting final demonstrations.			
Title: Rapid Array Development (RAD) ***Description:*** The Rapid Array Development (RAD) program seeks to build an immersive electromagnetic environment for use by the warfighter to understand the effects of electronic maneuvers and to develop new electronic maneuver warfare (EMW) techniques. In order to accomplish this, the program will leverage recent developments in flexible and adaptive radio frequency (RF) hardware, access to a larger variety of more powerful computing platforms, and advances in software virtualization to radically change the development and deployment cycle for EMW techniques. Currently, the development cycle for EMW algorithms is long and costly. However, they must be able to evolve rapidly in order to adapt to new modes of operation and changing operating parameters associated with modern military threats. The programmed RAD testbeds will ultimately train warfighters on how to deal with legacy and emerging threats in the RF spectrum through maneuvers, signal jamming tactics, signal intelligence gathering, and other missions. The outcome of RAD will be better tactics, techniques, and procedures for handling EMW as well as the identification of new technology assets for deploying EMW capabilities. Technologies developed under the RAD program are planned for transition to the Services through a series of demonstrations proving a radically shorter time scale of development. ***FY 2019 Plans:*** - Initiate development of a compute engine to optimize the implementation of electromagnetic (EM) algorithms on a system of heterogeneous processors. - Explore use of toolchains and toolsets for programming on heterogeneous computing systems. - Explore new models of machine learning and supervisory controls to manage complex allocation of processing resources. - Initiate development of flexible array technology to be the common hardware platform for an immersive applications development environment. ***FY 2020 Plans:***	-	18.500	19.779

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Initiate development of a processing platform capable of executing EMW algorithms, array configuration, data flow, and end-user interactions. - Develop a software framework for rapidly developing new EMW applications. - Initiate development of a full EMW mission control system to include electromagnetic spectrum monitoring and management. - Initiate plans for a testbed installation at a military base or radar test range and begin electromagnetic spectrum monitoring. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects the shift from exploring and initiating development to developing RAD software and the testbed environment.			
Title: Advanced PNT Capability Demonstrations (APCD) ***Description:*** Both the Microelectromechanical Systems (MEMS) and the atomic physics communities have done foundational research on new capabilities that will impact the ability to keep and transfer precision timing and navigation information across the battlefield. The Advanced PNT Capability Demonstrations (APCD) program will choose among the most promising of the new physics developments and demo their potential in realistic warfighting scenarios. One scenario will leverage advances in inertial sensors to enable Inertial Measurement Unit (IMU)-only operation over mission timeframes of twenty minutes. The MEMS-based demo will enable munitions navigation in a GPS-denied world, maintaining U.S. munition and missile capability to accurately navigate in future battlespace environments. Another scenario is the storing of time and position information with high performance yet compact, low power atomic physics. This will enable advanced Positioning, Navigation, and Timing (PNT) capabilities for example in a Low Earth Orbit (LEO) constellation, or an Unmanned Air Vehicle (UAV) from which the atomic based information can be distributed. Technologies developed under the APCD program are planned for transition to the Services. ***FY 2020 Plans:*** - Determine the most sophisticated demonstration highlighting the recent advances in MEMS and atomic physics. - Initiate design of the demonstrator and the subcomponents needed to perform the demonstration. - Develop IMU packaging and support circuitry with emphasis on program metrics including size, weight, stability, and power consumption. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.	-	-	9.500
Title: Efficient Ultra-Compact Laser-Integrated Diodes (EUCLID) ***Description:*** The Efficient Ultra-Compact Laser-Integrated Diodes (EUCLID) program aims to significantly reduce the size of laser diode pump modules (DPMs) while increasing their electrical-to-optical efficiency. DPMs are a critical component of fiber-laser array weapons systems, which combine light from many lower-power lasers to engage targets at tactically-relevant distances.	5.000	5.000	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Commercial DPMs, which cater to the laser manufacturing industry, feature large cooling systems and are too cumbersome for integration into many small DoD platforms. EUCLID plans to leverage advances in thermal management components to design, build, test, and demonstrate densely packageable, prototype DPMs that are less than half the size of their commercial counterparts. The program will also pursue improved optical components that can more efficiently focus light from individual laser diodes. The resulting EUCLID DPMs are intended to be available for procurement and integration into ultra-low size, weight, and power fiber-laser array weapons systems, enabling integration into a variety of Air Force, Navy, Army, and Missile Defense Agency platforms. ***FY 2019 Plans:*** - Build and test prototype DPMs which produce >4 kW of optical power and >58% efficiency and are suitable for powering a coherently combinable fiber laser amplifier assembly. - Generate detailed designs of a compact, packaged 4 kW diode pump assembly based on the prototype DPMs. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Title: Millimeter Wave Digital Arrays (MIDAS) ***Description:*** The Millimeter Wave Digital Arrays (MIDAS) program will develop a common millimeter wave phased-array tile that is scalable to large arrays to provide wideband frequency agility from 18-50 GHz with element-level digital beamforming. Millimeter wave systems are used today to achieve physical security through the use of narrow antenna beams in a small form-factor. We see this applied to satellite communications and tactical line-of-sight communications such as in the F-22 and F-35. One of the challenges of using directional communications in mobile applications is the problem of knowing where to point the antenna when both platforms are mobile. This can be solved with digital beamforming to enable a mobile platform to listen in all directions with many antenna beams to facilitate neighbor discovery when transmitting. Digital beamforming also enables multiple beams to communicate with several neighbors simultaneously. This capability will increase the network throughput and robustness that will be tolerant to unexpected outages. To achieve these goals, the program will develop a common digital phased array tile that can be used to build large arrays from this common block. The program will be executed in two primary technical areas. First, advanced complementary metal oxide semiconductor (CMOS) will be used to develop the core transceiver elements at a size and power consumption that is required to fit in the small size required by current millimeter wave systems. Second, a combination of advanced packaging and high-performance semiconductors will be used to build the wideband antenna and front-end amplifiers necessary to make a complete system. The MIDAS program moves to Project MT-16, Beyond Scaling Advanced Technologies, in FY 2019.	12.000	-	-
Title: Endurance	13.000	-	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Description: The Endurance program developed laser technology to protect airborne platforms from emerging and legacy electro-optical/infrared (EO/IR) guided surface-to-air missiles. Endurance has an open architecture, granting the flexibility to integrate different subsystems with varying capabilities. Endurance is an early application of technology developed through DARPA's Excalibur program. The advanced technology component of the program focused on developing and field testing various subsystems for laser beam generation, command and control, threat missile warning, target acquisition and tracking, beam control, energy storage and delivery, and thermal management. It also developed subsystem interfaces and integrated the components into a packaged system for field testing. Technologies from this program have transitioned to the Air Force.			
Accomplishments/Planned Programs Subtotals	73.673	67.838	58.279

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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603739E / *ADVANCED ELECTRONICS TECHNOLOGIES*	Project (Number/Name) MT-16 / *BEYOND SCALING ADVANCED TECHNOLOGIES*	

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
MT-16: *BEYOND SCALING ADVANCED TECHNOLOGIES*	-	0.000	43.261	70.337	-	70.337	73.000	66.900	52.000	52.000	-	-

A. Mission Description and Budget Item Justification

The Beyond Scaling Advanced Technologies Project is a continuation of DARPA's basic and applied research in this area and will support activities in large scale co-development with leading industry players to enable and accelerate transformative computing interactions with industry. Additionally, funding under this project will include establishing access to commercial state-of-the-art (SOTA) and state-of-the-practice (SOTP) foundries for DoD microelectronics fabrication runs, developing a manufacturable photonics and wide bandgap process, creating a microelectromechanical systems (MEMS) multi-project wafer flow, and establishing an application center to capture DoD microelectronics requirements.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Beyond Scaling - Access	-	30.200	51.137

Description: The Beyond Scaling - Access program will demonstrate the design and fabrication of advanced electronics through collaborations with leading industry players. Although the United States has led the development of advanced electronics since its inception and is home to three of the five leading-edge foundries, recent investments by foreign competitors are threatening this leadership. Additionally, the fabrication cost of next generation microelectronics has increased at an alarming rate. While the commercial sector is able to spread these costs over a large volume of products, the low volumes used by the DoD has led to a cost barrier in meeting its future technology needs. In some cases, the inability to place orders in volume has created a lack of access to advanced technology nodes entirely. To address this, the DoD must participate in more industry partnerships that not only leverage investments in the commercial industry but also provide access to SOTA facilities in the U.S. This program will build on existing relationships and forge forward-looking collaborations among the commercial electronics community, defense industrial base, university researchers, and the DoD. Activities include establishing access to commercial SOTA and SOTP foundries for DoD microelectronics fabrication runs, developing a manufacturable photonics and wide bandgap process, creating a microelectromechanical systems multi-project wafer flow, and establishing an application center to capture DoD microelectronics requirements. Technologies from this program are intended for transition to the Services.

FY 2019 Plans:
- Establish SOTA and SOTP microelectronics fabrication runs for DoD designs at leading-edge commercial foundries.
- Identify mixed-mode integrated circuit technologies for agile ultra-wide band systems.
- Initiate development of advanced process flows for multi-project wafer (MPW) runs at commercial MEMS manufacturers.
- Initiate implementation of a framework to capture applications requirements from DoD users.

FY 2020 Plans:

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 3	**R-1 Program Element (Number/Name)** PE 0603739E / *ADVANCED ELECTRONICS TECHNOLOGIES*	**Project (Number/Name)** MT-16 / *BEYOND SCALING ADVANCED TECHNOLOGIES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Demonstrate fabrication of DoD microelectronic designs from leading-edge commercial foundries. - Demonstrate high-speed, low latency mixed-mode integrated circuit components. - Demonstrate laser operation of an integrated photonic circuit using a manufacturable photonics process flow. - Demonstrate novel MEMS sensor, actuator, or filter designs through commercial MPW manufacturing processes. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects demonstration of multiple technologies fabricated through various commercial process flows.			
Title: Millimeter Wave Digital Arrays (MIDAS)	-	13.061	19.200
Description: The Millimeter Wave Digital Arrays (MIDAS) program will develop a common millimeter wave phased-array tile that is scalable to large arrays to provide wideband frequency agility from 18-50 GHz with element-level digital beamforming. Millimeter wave systems are used today to achieve physical security through the use of narrow antenna beams in a small form-factor. We see this applied to satellite communications and tactical line-of-sight communications such as in the F-22 and F-35. One of the challenges of using directional communications in mobile applications is the problem of knowing where to point the antenna when both platforms are mobile. This can be solved with digital beamforming to enable a mobile platform to listen in all directions with many antenna beams to facilitate neighbor discovery when transmitting. Digital beamforming also enables multiple beams to communicate with several neighbors simultaneously. This capability will increase the network throughput and robustness that will be tolerant to unexpected outages. To achieve these goals, the program will develop a common digital phased array tile that can be used to build large arrays from this common block. The program will be executed in two primary technical areas. First, advanced complementary metal oxide semiconductor (CMOS) will be used to develop the core transceiver elements at a size and power consumption that is required to fit in the small size required by current millimeter wave systems. Second, a combination of advanced packaging and high-performance semiconductors will be used to build the wideband antenna and front-end amplifiers necessary to make a complete system. Technologies from this program are intended for transition through commercial industry to the Services. The MIDAS program moved from Project MT-15, Mixed Technology Integration, in FY 2019. ***FY 2019 Plans:*** - Continue preliminary design review and initiate critical design review for fabricating a low-power, 16-element, element-level digital phased array at millimeter wave frequencies in advanced CMOS. - Develop and demonstrate a wideband and efficient power amplifier, low-noise amplifier and transmit/receive switch co-packaged with a wideband antenna array. - Explore more fundamental technical innovations relevant to millimeter wave digital arrays in the areas of converters, filters, oscillators, and broadband apertures. ***FY 2020 Plans:***			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 3	**R-1 Program Element (Number/Name)** PE 0603739E / *ADVANCED ELECTRONICS TECHNOLOGIES*	**Project (Number/Name)** MT-16 / *BEYOND SCALING ADVANCED TECHNOLOGIES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Begin design of a millimeter wave 64-element digital phased array in advanced CMOS with integrated power amplifiers and wideband aperture. - Demonstrate advancements in the fundamental technologies relevant to millimeter wave digital arrays in the areas of converters, filters, oscillators, and broadband apertures. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects the program going from exploring to demonstrating advancements in the fundamental technologies relevant to the millimeter wave digital arrays.			
Accomplishments/Planned Programs Subtotals	-	43.261	70.337

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 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 3: *Advanced Technology Development (ATD)*	**R-1 Program Element (Number/Name)** PE 0603760E / *COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS*

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	103.577	185.984	232.134	-	232.134	188.881	239.338	215.676	210.270	-	-
CCC-02: *INFORMATION INTEGRATION SYSTEMS*	-	45.168	105.316	133.539	-	133.539	112.617	181.705	204.268	210.270	-	-
CCC-06: *COMMAND, CONTROL AND COMMUNICATION SYSTEMS*	-	58.409	80.668	98.595	-	98.595	76.264	57.633	11.408	0.000	-	-

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 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, scalability, and composable systems to enable adaptive effects webs.
- 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. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	106.787	185.984	158.245	-	158.245
Current President's Budget	103.577	185.984	232.134	-	232.134
Total Adjustments	-3.210	0.000	73.889	-	73.889
• Congressional General Reductions	-6.750	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	3.933	0.000			
• SBIR/STTR Transfer	-0.393	0.000			
• TotalOtherAdjustments	-	-	73.889	-	73.889

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide I* BA 3: *Advanced Technology Development (ATD)*	**R-1 Program Element (Number/Name)** PE 0603760E *I COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS*

Change Summary Explanation

FY 2018: Decrease reflects Congressional reduction, SBIR/STTR transfer, offset by reprogrammings.

FY 2019: N/A

FY 2020: Increase reflects initiation of the Information Based Multi-level secure Mosaics (IBM2), Composable Logistics and Information Omniscience (LogX), Decomp/Recomp programs, and classified program expansion.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
CCC-02: *INFORMATION INTEGRATION SYSTEMS*	-	45.168	105.316	133.539	-	133.539	112.617	181.705	204.268	210.270	-	-

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, scalability, and composable systems to enable adaptive effects webs.
- 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 2018	FY 2019	FY 2020
Title: Secure Handhelds on Assured Resilient networks at the tactical Edge (SHARE)	13.042	28.996	22.942
Description: The goal of the Secure Handhelds on Assured Resilient networks at the tactical Edge (SHARE) program is to develop innovative networking and information sharing approaches that enable U.S. and coalition forces to coordinate tactical operations effectively, efficiently, and securely by eliminating today's prohibitive security cost and complexity barriers. SHARE will provide the level of security provided by today's communications systems, while managing trust at the tactical edge. Building upon the Spectrum Efficiency and Access program, which is budgeted in this PE/Project, and research into the use of commercial systems and infrastructure to support military operations, SHARE provides new opportunities for U.S. and coalition forces to gain and maintain a tactical advantage on the battlefield. Coordination includes providing all the information required to enable the command and control necessary to plan and execute operations in all phases of warfare. Technology from this program will transition to the Services and DoD Agencies that work with coalition partners.			
FY 2019 Plans: - Integrate and test multi-level, handheld software and new networking architecture supporting the sharing of information at multiple security levels. - Evaluate user interfaces with operational transition partners. - Conduct controlled, limited field experimentation on handheld devices, demonstrating multi-level secure information sharing and network security. - Develop and update automated network configuration software, ensuring compatibility with handheld and network approach.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Conduct system security assessment and compliance with overall program sharing and security objectives. ***FY 2020 Plans:*** - Conduct research and experimentation using SHARE software prototype that further supports creation of automated network configuration software. Experiments will test compatibility with existing operationally deployed handheld devices. - Conduct field experimentation during multiple DoD-sponsored coalition exercises to validate SHARE system security and performance. - Begin transition of SHARE software to DoD partners, e.g. the joint Tactical Assault Kit (TAK) development team, for follow-on software configuration management and accreditation for use on approved DoD handheld systems. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects a shift from research to integration of SHARE technologies into existing handheld programs.			
Title: Dynamic Network Adaptation for Mission Optimization (DyNAMO)	14.643	20.965	18.985
Description: Wireless networks have evolved into complex systems having many configurable parameters and 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 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 2019 Plans:*** - Continue development and integration of initial instantiation of real-time optimization algorithms in radio hardware. - Conduct hardware-in-the-loop testing of integrated system with instantiations of inter-network coordination, mission-based control, and real-time optimization. - Integrate final instantiation of inter-network coordination, mission-based control, and real-time optimization algorithms in radio hardware. - Conduct ground test of integrated system.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Conduct field test of integrated system with instantiations of inter-network coordination, mission-based control, and real-time optimization to show the quantitative and qualitative value of DyNAMO for a variety of military missions. ***FY 2020 Plans:*** - Integrate program software into tactical radio hardware. - Demonstrate Army, Navy, and Air Force scenarios. - Demonstrate information hyperlayer over diverse networks with publish/subscribe services. - Complete final program demonstrations and transition activities that demonstrate both interoperability and ability to adapt to real-time degradations and changing user needs. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects final demonstrations and completion of proof of concepts.			
Title: Geospatial Cloud Analytics (GCA)	7.032	21.965	19.993
Description: The Geospatial Cloud Analytics (GCA) program will develop technology to access and analyze global-scale, multimodal geospatial data and pilot an analytics-as-a-service business model. Exploiting multiple sources and modalities at a global scale requires the development of technologies and systems that provide common access points to commercial data, computational power to preprocess data and make it exploitable by analytical tools, and new models supporting sensing and analytics as services, including sharing of tools and results between individuals and consortiums. GCA creates a capability for near real time monitoring of global events and change detection across various environments and warfighting domains, building upon the Secure Handhelds on Assured Resilient networks at the tactical Edge (SHARE) coalition warfighter information sharing program, also budgeted in this PE/Project. By exploiting the vast amounts of geospatial information from new commercial satellite constellations and other sources, GCA will create the technology foundations needed to provide global awareness of gray zone activities. It will do so by augmenting commercial capabilities with defense assets, not vice versa, and thereby will improve speed, agility, and scalability. Technology from this program will transition to the Services and DoD Agencies. ***FY 2019 Plans:*** - Analyze computational architectures and frameworks for GCA analytics services at global scale. - Demonstrate the ability of the software infrastructure to support global-scale analytics on relevant problem sets. - Demonstrate gray zone indicators and warnings for high-impact, destabilizing global events such as droughts, crop failures, and illegal fishing. - Experiment with approaches for offering analytics services for use by DoD users and others. ***FY 2020 Plans:*** - Create and test an analytics marketplace that combines the multi-source, multi-modality platform with global-scale analytics. - Demonstrate ability for DoD users to use the analytics services provided by the analytics marketplace.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- Refine the analytics services and marketplace based on feedback from end users. - Begin development of additional future marketplace offers based on feedback from end users. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects a shift from platform and software development into testing of the analytics marketplace.			
Title: Network Universal Persistence (Network UP) ***Description:*** Current radios send network control information and data using the same wireless link. This produces a common failure mode when that wireless link degrades. In many of today's military wireless networks, even brief wireless link outages create a loss of network connectivity that can take more than two minutes to recover once the wireless link is re-established. During these network outages, data transmission is not possible. Building on technologies explored in the Secure Handhelds on Assured Resilient networks at the tactical Edge (SHARE) program, also in this PE/Project, the Network UP program will develop and demonstrate radio technology that maintains network reliability through periods of frequent signal degradation that routinely occur in military operational environments. Isolation of critical control channel information in a separate, robust wireless link will allow creation of a protected control channel that can maintain network reliability even when the data channel is lost. The Network UP program will develop technology and a prototype system that enables military wireless networks to send data over dynamic, unstable wireless links. The program will develop approaches to separate the control and data planes across different wireless links and design and implement mechanisms to maintain synchronization across those separate links. Technologies developed under this program will transition to the Services. ***FY 2019 Plans:*** - Begin preliminary design of a radio architecture and supporting technology that implement separate control and data channels. - Begin preliminary design of network architectures and technologies that enable creation of a network with physically separated control and data links. - Begin early lab testing of radio and network architectures and technology approaches. ***FY 2020 Plans:*** - Demonstrate a communication system that provides reliable communications in the presence of jamming. - Demonstrate physical communications channel divided into two separate functions and radio frequency bands. - Complete design of radio architectures and build and test prototypes. - Complete design of network architectures and build and test prototypes. - Demonstrate radio architectures in highly mobile scenarios with large amounts of environmental attenuation. ***FY 2019 to FY 2020 Increase/Decrease Statement:***	-	12.377	20.964

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
The FY 2020 increase reflects increased effort dedicated to prototype building and testing.			
Title: Protected Forward Communications (PFC)	-	12.593	19.580
Description: The collaborative application of combat power in ground tactical operations demands reliable exchange of rich information and precise coordination of actions across various echelons. These operations take place over three critical conversations: (1) to coordinate the actions of a local group, (2) to coordinate group and airborne assets, and (3) to interact with rear echelon command. The communication links over which these three conversations take place are at risk from jamming and geolocation operations conducted with increasingly sophisticated exploitation and denial technology employed by our adversaries. This problem is compounded by demands for ever-increasing capacity of these links. The Protected Forward Communications (PFC) program will build on technical advances in resilient, efficient, and aware communications technology to design a single communication architecture to protect all three conversations from jamming and geolocation. PFC builds on technology developed in the Secure Handhelds on Assured Resilient networks at the tactical Edge (SHARE) program, also budgeted in this PE/Project. PFC is generally applicable to small unit operations and is particularly relevant to the close air support (CAS) function typically executed by the Joint Terminal Attack Controller (JTAC) or Forward Air Controller (FAC). The PFC program will transition to the Services. ***FY 2019 Plans:*** - Commence algorithm design for implementation and control of all three communication techniques. - Begin concept validation through modeling and simulation. - Establish readiness of constituent link technologies for all three communication techniques. ***FY 2020 Plans:*** - Conduct simulation and modeling of systems in representative operating environments to assess resistance to geolocation and jamming. - Conduct system engineering reviews to ensure design readiness for further development. - Conduct experimental validation of key design elements. - Develop size, weight, and power estimates for complete prototype and complete system. - Produce fully qualified design of PFC communication system with data artifacts. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects a shift from modeling and simulation to experimental and demonstration validation.			
Title: Information Based Multi-level secure Mosaics (IBM2)	-	-	10.365
Description: Information Based Multi-level secure Mosaics (IBM2) will develop network and data management tools for automating establishment of cross-domain networks and managing information flow to support on-the-fly adaptive effects webs.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
Today the operational configure time required to make systems share information in battle, even when using networks designed to interoperate, is on the magnitude of weeks to months, but effective joint multi-domain battle integration time is needed in minutes or faster. Technology advances are making it possible to pass messages across heterogeneous waveforms and networks, but there are no technologies today that can determine if it is the right data most important to end users and systems. Building upon technologies developed in the Dynamic Network Adaption for Mission Optimization (DyNAMO) program (budgeted in this PE/ Project), IBM2 will combine network management with information exploitation and fusion technology to route information in an understandable context, based upon information need and value. IBM2 also seeks to address multi-level security configuration issues that often add delays and limit interoperability. Technology developed by this program will transition to the Services. ***FY 2020 Plans:*** - Assess effectiveness of machine learning, artificial intelligence (AI) techniques for understanding context and information value at user, system, and mission nodes. - Begin development of algorithmic techniques for determining global information relevance and importance and converting it to local context. - Begin development of algorithms for auto-generating security labels for multi-level security gateways as appropriate for protecting sources. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** Increase in FY 2020 reflects program initiation.			
Title: Composable Logistics and Information Omniscience (LogX) ***Description:*** The Composable Logistics and Information Omniscience (LogX) program will develop planning and execution software to enable resilient and survivable logistics. The software will integrate enhanced situational awareness, dynamic composition of sustainment options, and accelerated Course of Action (COA) development. Based upon technologies developed in the Prototype Resilient Operations Testbed for Expeditionary Urban Systems of Systems (PROTEUS) program (budgeted in PE 0603766E, Project NET-01), the LogX capability will allow users to achieve a more distributed and resilient logistics command and control (C2) system utilizing planned cloud-based data environments. The new capability will be tested in an experimental environment tied to current logistics datasets. Technologies from this program will be transitioned to the Services, combatant commands, including U.S. Transportation Command. ***FY 2020 Plans:*** - Initiate development of situational awareness, composition, and COA development tools. - Demonstrate standalone capability for using only enterprise situational awareness.	-	-	9.365

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Begin integration of test environment with limited complexity logistics data set. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.			
Title: Decomp/Recomp ***Description:*** A future Joint Multi-Domain Battle force must be able to interoperate amongst heterogeneous systems rapidly, as well as use those systems in new ways. The battle network must be able to access latent capability provided by existing systems to build and close a wide range of effects chains. Resources in the battlespace will need to be repurposed with minor modification in ways for which they may not have been initially designed to create new capability without resorting to traditional acquisition. The Decomp/Recomp program will develop technology to enable efficient software modification to enable the integration or adaptation of electronic military systems to create new capability rapidly. Using techniques developing in the commercial software community and building on insights developed in the System of Systems Integration Technology Experimentation (SoSITE) program (budgeted in PE0603766E/Project NET-01); technology developed under the Decomp/Recomp program will decompose existing programmable military electronic system software into building blocks that can be rapidly reassembled into new, interoperable functions. The program will ensure performance reliability meets mission expectations with minimal to no formal validation and verification. The program aims to provide this degree of integration and adaptation on mission-relevant timelines, hours to days instead of months to years. Technologies developed under this program will transition to the Services. ***FY 2020 Plans:*** - Begin to demonstrate, through modeling and simulation, ability to identify mission capability from component systems. - Begin development of automated processes to validate and verify that adapted applications perform as intended when installed during demonstrations. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.	-	-	11.345
Title: 100 Gb/s RF Backbone ***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 capacity needs of deployed military forces. 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	3.233	2.433	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
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 Optical RF Communications Adjunct (ORCA) system. Technology developed under this program will transition to the Services and other government agencies. ***FY 2019 Plans:*** - Integrate prototype onto test aircraft and conduct air-to-ground testing. - Complete air-to-ground testing and conduct flight demonstrations. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Title: Spectrum Efficiency and Access ***Description:*** The Federal Government is 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 sensor and data 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 and radar bands with communication systems. The program will leverage technologies originally developed for radar anti-jam and interference mitigation 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 transition to the Navy, Army, and Missile Defense Agency (MDA). ***FY 2019 Plans:*** - Demonstrate spectrum maneuver command and control concepts. - Finalize design of a system capable of dynamically controlling radio frequency signatures while maintaining high accuracy target tracking. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.	6.059	5.987	-
Title: Communication in Contested Environments (C2E) ***Description:*** The Communication in Contested Environments (C2E) program sought 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 strained the size of networks that current communications technology could support in the contested environment. As adversary capabilities advanced, the DoD needed new techniques to quickly and efficiently	1.159	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
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 addressed these needs with a three-pronged approach: first, it developed 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 were developed. Second, the program created a government controlled and maintained reference architecture for communications systems that drew from commercial communication architectures. The defense contractor community built specific communications systems based upon this reference architecture. Finally, C2E created a government controlled development environment to allow for rapid refresh of communications technology and allowed third party native application and waveform developers to contribute their own communications technologies. Technologies from this program transitioned to the Navy.			
Accomplishments/Planned Programs Subtotals	45.168	105.316	133.539

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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603760E / *COMMAND, CONTROL AND COMMUNICATIONS SYSTEMS*	Project (Number/Name) CCC-06 / *COMMAND, CONTROL AND COMMUNICATION SYSTEMS*	

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
CCC-06: *COMMAND, CONTROL AND COMMUNICATION SYSTEMS*	-	58.409	80.668	98.595	-	98.595	76.264	57.633	11.408	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 2018	FY 2019	FY 2020
Title: Classified DARPA Program	58.409	80.668	98.595
Description: This project funds Classified DARPA Programs. Details of this submission are classified.			
FY 2019 Plans: Details will be provided under separate cover.			
FY 2020 Plans: Details will be provided under separate cover.			
FY 2019 to FY 2020 Increase/Decrease Statement: Details will be provided under separate cover.			
Accomplishments/Planned Programs Subtotals	58.409	80.668	98.595

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.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	429.691	434.069	512.424	-	512.424	447.162	428.781	401.315	397.315	-	-
NET-01: *JOINT WARFARE SYSTEMS*	-	75.460	99.963	99.487	-	99.487	162.805	179.345	167.590	193.992	-	-
NET-02: *MARITIME SYSTEMS*	-	123.462	110.363	132.484	-	132.484	105.909	160.550	189.725	193.323	-	-
NET-06: *NETWORK-CENTRIC WARFARE TECHNOLOGY*	-	230.769	223.743	280.453	-	280.453	178.448	88.886	44.000	10.000	-	-

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 is identifying, developing and rapidly maturing 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.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide I* BA 3: *Advanced Technology Development (ATD)*	**R-1 Program Element (Number/Name)** PE 0603766E *I NETWORK-CENTRIC WARFARE TECHNOLOGY*

B. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	439.386	438.569	451.035	-	451.035
Current President's Budget	429.691	434.069	512.424	-	512.424
Total Adjustments	-9.695	-4.500	61.389	-	61.389
• Congressional General Reductions	0.000	-4.500			
• 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	-0.554	0.000			
• SBIR/STTR Transfer	-9.141	0.000			
• TotalOtherAdjustments	-	-	61.389	-	61.389

Change Summary Explanation

FY 2018: Decrease reflects SBIR/STTR transfer and reprogrammings.

FY 2019: Decrease reflects Congressional reduction.

FY 2020: Increase reflects initiation of the Heterogeneous UnderWater Communications (HUWC), Maritime Missileer and Angler programs, and classified program expansion.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
NET-01: *JOINT WARFARE SYSTEMS*	-	75.460	99.963	99.487	-	99.487	162.805	179.345	167.590	193.992	-	-

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 2018	FY 2019	FY 2020
Title: System of Systems Integration Technology and Experimentation (SoSITE)	29.362	24.594	13.999
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 leverage an integrated set of system characteristics and capabilities. The demonstration assessment metrics will measure individual and combined system performance to 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 2019 Plans: - Secure test articles for flight test experiments of distributed strike and suppression of enemy air defenses using manned and unmanned platforms and experimental mission systems.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Demonstrate the capability of new engineering tools to validate system of systems architecture designs prior to live flight experiments. - Demonstrate the capability of formal verification techniques to validate integration of constituent systems into a system of systems prior to live flight experiments. - Conduct integration events to characterize sub-systems digitally to enable rapid integration into systems of systems. - Conduct live flight experiments of system of systems architectures for networked electronic attack, distributed strike, and suppression of enemy air defense missions. - Apply advanced software integration methods to enable rapid upgrade and improve portability of both new and legacy aircraft platform software. ***FY 2020 Plans:*** - Deploy SoSITE integration technologies, called STITCHES (System of Systems Technology Integration Tool Chain for Heterogeneous Electronic Systems), to a DoD-accredited cloud hosted repository. - Implement upgrades to toolchain required by transition partners, including technology to allow full backwards and forwards compatibility of all versions of the toolchain. - Transition of SoSITE STITCHES toolchain to multiple operational Service partners. - Perform final live flight experiments of system of systems architectures. - Conduct final integration events to enable rapid integration into systems of systems. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects a decrease in flight demonstrations to a focus on toolchain demonstrations.			
Title: Resilient Synchronized Planning and Assessment for the Contested Environment (RSPACE)	20.772	16.869	11.345
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 and models 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. RSPACE will also develop tactical decision aids for maritime commanders and planners to build and assess courses of action (COAs) for fleet and ship movements and the employment of counter-ISR techniques. 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			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
tools will dynamically respond as directed to ad hoc requests and significant plan deviations via a real-time dynamic re-planning capability and easily adapt to technology refreshes. RSPACE tools will transition to the Air Force and the Navy. ***FY 2019 Plans:*** - Conduct one or more live-virtual simulation-based tests in conjunction with a scheduled live Air Force experiment to facilitate transition to the Air Force. - Integrate prototype software with external systems and scale to large, high operational tempo scenarios. - Enhance models and user support interfaces in preparation for transition to operational testing by the Navy. ***FY 2020 Plans:*** - Complete software development in support of transition of select RSPACE software components to Air Force Program of Record. - Complete testing of software with Air Force in support of transition. - Complete integration with external Air Force systems in support of transition. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects decreased scope of software development, integration, and testing due to emphasis on transition to the Air Force.			
Title: Prototype Resilient Operations Testbed for Expeditionary Urban Systems of Systems (PROTEUS)	14.361	17.285	18.480
Description: The Prototype Resilient Operations Testbed for Expeditionary Urban Systems of Systems (PROTEUS) program will demonstrate that a dynamically composable Mosaic warfare approach provides superior performance and adaptability in the dynamic, uncertain environment imposed on U.S. warfighters by urban combat operations. PROTEUS will provide the tools and automation to enable small tactical units to compose force packages optimized to specific urban combat objectives and challenges. These tools will support planning and force composition for all missions relevant to the urban environment: command & control, fires, maneuver, logistics, intelligence, force protection, and medical. PROTEUS will be adaptive to an inherently dynamic and fluid environment that will account for the environmental influence of non-combatants in urban combat as well as kinetic warfighting. Technologies will be integrated using systems of systems principles developed under the System of Systems Integration Technology and Experimentation (SoSITE) program, budgeted in this PE/Project. To support concept development, testing, and warfighter interaction, the program will also develop a supporting virtual testbed. Technologies from this program will be transitioned to the Services. ***FY 2019 Plans:*** - Develop a multi-resolution scenario within the virtual testbed and compare outcomes against a Marine Corps exercise benchmark.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Define friendly and opposing force systems for kinetic functions. - Demonstrate integration of the virtual testbed and the composition tool using the benchmarked scenario. - Demonstrate adaptive composition capability with Service participants. - Commence development of mathematical tools to define and score the value of materiel in a logistics flow. ***FY 2020 Plans:*** - Begin development of planning and force composition tools for spectrum and intelligence operations. - Demonstrate integration of the virtual testbed and composition tool using multi-resolution scenarios with increased complexity. - Demonstrate enhanced adaptive composition capability with Service participants. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects the shift in focus to testing and extension of previous developed capabilities.			
Title: Systems of Systems-Enhanced Small Units (SESU)	-	11.215	18.385
Description: The System-of-Systems-Enhanced Small Unit (SESU) program will develop and demonstrate adaptive kill-web capabilities based on a system-of-systems architecture that enables a small unit of U.S. forces to prevail against a much larger near-peer adversary force in a contested environment. SESU-developed capabilities will provide the small unit with improved awareness of enemy force composition, disposition, and intent. It will also provide the means to deter escalation of threat, and, if deterrence fails, the ability to degrade, disrupt, and/or destroy enemy anti-access / area denial and combat systems. Technologies to accomplish this include command & control (C2) that operates in a contested environment; distributed sensing, including the ability to leverage indigenous information sources; hybrid effects that include a mix of kinetic, non-kinetic, and information operations capabilities; and autonomous systems to deliver effects and conduct sensing. A Campaign of Learning (CoL) will be conducted in partnership with the Army, and technologies produced by this program will be transitioned to the Services. ***FY 2019 Plans:*** - Complete SESU architecture definition and develop evaluation scenarios. - Demonstrate baseline technologies in a simulated environment. - Initiate design of key technologies (e.g. distributed C2, sensors, and effectors). - Conduct virtual war games that combine modeling and simulation with table top exercises to develop performance metrics, concepts. ***FY 2020 Plans:*** - Integrate modeling and simulation environment and evaluate baseline and advanced architecture performances based on selected scenarios. - Demonstrate impact of advanced technology suites.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Down select from designs based on performance and begin development of prototypes with distributed C2, sensors, and effectors. - Develop plan for live field experimentation for CoL. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects the development of prototypes.			
Title: Assault Breaker II (ABII) ***Description:*** Assault Breaker II (ABII) seeks to change the current warfighting paradigm of reliance on Service-specific, platform-centric force executing prescribed kill chains to a highly adaptable, capability-based force operating as a disaggregated kill web able to execute rapidly composable, cross domain kill chains. Building upon technologies developed in the Cross Domain Maritime Surveillance and Targeting (CDMaST) program, budgeted in this PE, Project NET-02, ABII will exploit both existing and emerging technologies across the Services to address known capability gaps, opportunities and threats. ABII will conduct mission-centric, multi-Service and multi-domain analysis, modeling and simulation (M&S), and experimentation to inform research and development and program of record recommendations, and will build an enduring, multi-service M&S environment to support complex, mission level kill web analysis. ABII technologies will transition to the Services. ***FY 2019 Plans:*** - Initiate initial kill web analysis studies and deliver preliminary advanced kill web technologies program recommendation report. - Complete multi-domain, multi-level security environment survey and analysis of alternatives study. - Initiate preliminary design of multi-domain, multi-level security environment. ***FY 2020 Plans:*** - Complete initial kill web analysis studies and deliver updated advanced kill web technologies program recommendation report. - Initiate second round of kill web analysis studies to support kill web architecture refinement. - Complete preliminary design of multi-domain, multi-level security environment. - Initiate detailed design of multi-domain, multi-level security environment. - Complete preliminary experimentation plan. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects increased multi-domain, multi-level security environment design efforts.	2.000	10.000	18.000
Title: Glide Breaker ***Description:*** Glide Breaker will develop critical component technologies to support a lightweight vehicle designed for precise engagement of hypersonic threats at very long range. Phase I of the program focuses on a single, critical, long-lead technology with applicability to a variety of interceptor concepts and designs. Phase II will build on the success of Phase I, developing	-	20.000	10.000

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
additional component technologies and laying needed groundwork for an integrated demonstration which will showcase the system's ability to defeat adversary hypersonic weapons. ***FY 2019 Plans:*** - Conduct Preliminary Design Review (PDR) for technology demonstration. - Execute trade studies to identify key technologies and estimate system performance. - Complete critical design review for technology demonstration. ***FY 2020 Plans:*** - Complete component level bench testing for long lead technology demonstration. - Complete test readiness review for critical, long-lead technology demonstration. - Initiate development of selected key technologies. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY20 decrease reflects completion of preliminary and critical design and trade studies and transition to bench testing and development of key technologies.			
Title: Air Combat Evolution (ACE) ***Description:*** As the Services develop new Joint Multi-Domain Battle warfighting concepts, there is a strong demand for innovative ways to perform experimentation in order to assess architectures, advance technology, and support operators developing advanced multi-domain tactics. Current infrastructure and technology do not support experimentation with distributed heterogeneous systems. Based upon technologies developed in the System of Systems Integration Technology and Experimentation (SoSITE) program, budgeted in this PE/Project, the Air Combat Evolution (ACE) program will apply technologies and principles of interoperability, autonomy, and artificial intelligence (AI) to develop an experimentation infrastructure that will allow for the integration of various modeling and simulation (M&S), sub-scale, and ultimately full-scale vehicles in dynamic aerial combat environment. The program will deliver an initial instantiation of a scalable experimentation engine capable of aircraft control at levels ranging from an advanced tactical autopilot to a form of multi-domain mosaic controller. Experiments will explore both augmentation of existing manned platforms and increased capabilities and intelligence of future unmanned systems. ACE will provide an early opportunity to experiment with adaptive human-machine teaming to deliver tools and architectures as the Joint Multi-Domain Battle concept evolves within the Services. Higher-fidelity simulated adversary human behavior will also be developed to ensure blue operators conducting experiments are faced with more realistic dilemmas posed by computer-played adversaries. Technology developed by this program will transition to the Services. ***FY 2020 Plans:*** - Conduct exploratory trade studies to establish feasibility of technical approaches.	-	-	9.278

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Adapt autonomy and AI technology to modeling and simulation experimentation infrastructure. - Initiate Service outreach to inform and synchronize the experimentation portfolio. - Evaluate commercial, gaming agent-based AI technology to provide higher-fidelity human behavior modelling. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.			
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 was to develop and demonstrate the capability to combine distributed mobile transmitters to direct high-power spatially resolved radio frequency (RF) beams to a single location. ReACT provides this capability by synchronizing multiple distributed transmitters to form a much larger effective array than a single aperture. The key technical challenge was to synchronize distributed and moving transmitters while compensating for platform motion and vibration. The ReACT system sensed the target's emissions and then optimally configured the ReACT transmitters to focus on the area of interest. Technologies from this program transitioned to the Air Force and Navy.	8.965	-	-
Accomplishments/Planned Programs Subtotals	75.460	99.963	99.487

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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
NET-02: *MARITIME SYSTEMS*	-	123.462	110.363	132.484	-	132.484	105.909	160.550	189.725	193.323	-	-

A. Mission Description and Budget Item Justification

The objective of the Maritime Systems project is identifying, developing, and rapidly maturing 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 2018	FY 2019	FY 2020
Title: Cross Domain Maritime Surveillance and Targeting (CDMaST)	30.841	29.732	24.987

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 and develop a robust "kill web" 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. The 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 CDMaST program will invest in technologies that will reduce cost, manage complexity, and improve reliability. Technologies from this program will transition to the Navy.

FY 2019 Plans:
- Integrate system of systems assets and perform operational tests leading to at-sea demonstrations of CDMaST capability to facilitate transition to the Navy.
- Continue to refine the CDMaST architecture segments and service layers.
- Continue to conduct elemental, engineering, and operational tests on selected segments of the CDMaST architecture.
- Complete planning for at-sea demonstrations of the CDMaST architecture.

FY 2020 Plans:
- Complete system integration.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Complete software-in-the-loop system testing. - Complete CDMaST testbed. - Conduct at-sea demonstrations of the CDMaST architecture. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects completion of testbed development.			
Title: Positioning System for Deep Ocean Navigation (POSYDON) ***Description:*** 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 the ocean 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. The POSYDON program will distribute a small number of acoustic sources, analogous to GPS satellites, around an ocean basin at known locations. A submarine or AUV will be equipped with an acoustic receiver and appropriate software in order to obtain and maintain 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 calculate its position. Technologies developed under this program will transition to the Navy. ***FY 2019 Plans:*** - Design and test a prototype POSYDON system. - Demonstrate real-time positioning for relevant AUV platforms. - Document results of at-sea testing to support systems integration. ***FY 2020 Plans:*** - Transition POSYDON hardware to Navy undersea test bed. - Demonstrate mission planning tool to guide system employment. - Conduct modeling and simulation to demonstrate concept of operations for deep and littoral mission. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects completion of final analysis after at-sea demonstration.	20.518	19.580	14.719
Title: Hunter ***Description:*** The Hunter program seeks to develop novel concepts for Extra Large Unmanned Undersea Vehicles (XLUUVs) to deliver complex payloads. The program will explore efficient encapsulation and buoyancy control concepts to be implemented with advanced fiber handling capabilities for high bandwidth communications in order to create a highly modular and adaptable	16.979	27.525	23.742

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
ocean interface. This interface will give XLUUVs significantly increased payload handling ability and allow them to deliver completely new capabilities previously delivered only by manned platforms. Building upon research conducted under the Cross Domain Maritime Surveillance and Targeting (CDMaST) program budgeted in this PE/Project, the Hunter program will establish a new capability for integration into maritime system of systems warfare architectures. Technologies developed under the Hunter program will transition to the Navy. ***FY 2019 Plans:*** - Complete design of Hunter payload delivery carriage. - Build partial carriage payload delivery system to support risk reduction testing. - Commence fabrication of Hunter payload delivery carriage. - Perform stand-alone in-water test of partial Hunter payload delivery carriage. - Apply information assurance measures to Hunter payload delivery carriage. ***FY 2020 Plans:*** - Complete fabrication of carriage system. - Develop full Hunter system and information assurance implementation test plan. - Perform stand-alone in-water test of full Hunter payload delivery carriage. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects completion of system fabrication and entry into the integration and testing phase.			
Title: Ocean of Things ***Description:*** The goal of the Ocean of Things program is to advance oceanographic sensing and battlespace awareness using low-power microelectronics and advanced data analytics. Ocean of Things builds upon advances made in the Cross Domain Maritime Surveillance and Targeting (CDMaST) program, budgeted in this PE/Project. Ocean of Things will develop large numbers of heterogeneous sensing floats to cover large ocean areas, while incorporating environmentally friendly construction materials. These platforms will leverage satellite communications to populate a large data repository with sensor outputs for shared processing. Ocean of Things will apply advanced analysis techniques to the stored data to synthesize and discover new signals and behaviors in the ocean environment. The program will research the spatio-temporal composability of sensors and develop applications for distributed platform behavior using an internet of things (IoT) architecture deployed across the world's oceans. Further research will examine additional platform capabilities and system impacts of communication rate and edge processing. The Ocean of Things program will improve ocean awareness and provide persistent coverage to areas between existing platforms. Technologies developed in Ocean of Things will transition to the Navy. ***FY 2019 Plans:***	-	11.000	25.933

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Conduct initial data architecture studies to determine optimal host and service platform. - Conduct initial sensor and payload studies to examine optimal sensor and payload types for platform configurations. - Develop initial hardware design and sensor configurations for test platform delivery. - Demonstrate and test initial sensors through small-scale ocean float deployment. ***FY 2020 Plans:*** - Develop advanced platform design. - Research active sensor behaviors for potential inclusion into advanced system design. - Demonstrate and test advanced sensors through large-scale ocean float deployment. - Develop government data cloud and architecture, model ocean inputs, and apply initial machine learning applications. - Develop visualization of machine learning results for military application. - Evaluate test data to determine performance and coverage in the ocean. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects moving from development to a large-scale at-sea float deployment.			
Title: Heterogeneous UnderWater Communications (HUWC) ***Description:*** Integration of undersea elements for joint cross-domain operations is critical for developing the most effective distributed kill webs. The Heterogeneous UnderWater Communications (HUWC) program will create an undersea internet that will span the ocean and bridge to other operating domains. Building upon technologies learned in the Tactical Underwater Network Architecture program, budgeted in this PE/Project, HUWC will provide an adaptive, heterogeneous, highly-connected network capability to link undersea and cross-domain assets together into kill webs and will establish and maintain these networks with minimal operator burden. The program will leverage recent technological developments demonstrating short-range and long-range acoustic communications at higher bandwidth and greater reliability, while minimizing detectability. The program will also leverage recent developments in network interoperability to manage heterogeneous undersea and cross-domain networks. Technology developed by this program will transition to the Navy. ***FY 2020 Plans:*** - Conduct modeling and simulation to determine optimal network configuration. - Begin development of heterogeneous network architectures comprised of acoustic and non-acoustic elements. - Begin development of algorithms to adapt networks to mission and environment. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.	-	-	11.778
Title: Maritime Missileer	-	-	16.325

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
Description: The Maritime Missileer program will develop small, low-cost, disaggregated naval platforms to demonstrate the ability to perform persistent power projection and force application combat missions currently conducted from large, high-value capital ships. This network of platforms will project power and provide sea control across the spectrum of conflict, presenting potential adversaries with a dramatically different and rapidly reconfigurable order of battle. Maritime Missileer is envisioned as a family of heterogeneous systems, incorporating advanced autonomy and artificial intelligence to permit stand-in operations in even the mostly heavily contested environments. Effects are delivered with novel approaches to achieving mobility, potentially leveraging innovations in commercial shipbuilding and logistics, and platforms may vary from unmanned, to optionally manned, to manned. Technologies to be developed include advanced propulsion, energy sources for long-term operations, autonomous re-arming and re-fueling, self-maintenance, high-reliability communications, as well as hardware and software approaches to enhance system reliability, adaptability, and autonomous self-defense/anti-tamper. ***FY 2020 Plans:*** - Develop concept of operations. - Identify critical technologies. - Design and develop representative platforms. - Design and develop critical technologies. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.			
Title: Angler	-	-	15.000
Description: The undersea domain has significant importance to national security and military operations. Yet it is a challenging domain in which to operate due to extreme water pressures, restricted communications, ever changing bottom environments, marine fouling and corrosion. The Angler program seeks to improve U.S. operations in this domain by enabling underwater robotic systems significantly ahead of the state of the art. These robotic systems would be able to search and manipulate objects autonomously, even in dark, turbulent, and semi-opaque sea conditions without the need for human control and without reliance on the Global Positioning System (GPS). Key Angler technical challenges include sensing techniques that provide high-resolution navigation without GPS, perception and manipulation strategies for objects with unknown parameters, long duration autonomy approaches to support mission execution, and autonomy approaches that do not rely on human intervention. This program also has a companion applied research effort budgeted in PE0602702E, Project TT-03. The anticipated transition is to the Navy. ***FY 2020 Plans:*** - Perform subsystem integration and test.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Demonstrate and test robot system prototypes in a structured maritime environment. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects initiation of advanced technology development activities.			
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 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 and novel low probability of intercept/low probability of detection (LPI/LPD) communication signaling. In addition, the MOCCA system will be integrated into submarine onboard sonar and weapons control systems. Technologies from this program will transition to the Navy. ***FY 2019 Plans:*** - Complete system utility analysis to identify optimal performance specifications for concept of operations under multiple tactical situations. - Integrate MOCCA communications transmission and processing approach onboard a submarine for at-sea feasibility demonstration. - Conduct at-sea feasibility demonstration to evaluate MOCCA communications transmission and processing approach using Navy assets. - Coordinate with the Navy to define concepts of operations. - Transition MOCCA communications and sonar systems to the Navy. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.	14.366	7.094	-
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	13.430	7.733	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
and prevent the full exploitation of the potential of undersea systems. The Tactical Undersea Network Architectures program will overcome these limitations by developing the technologies necessary for autonomous, reliable, and secure undersea data transfers; true plug, play, and operate standards; and rapid, cost-effective deployment technologies. The program will develop and demonstrate novel technology options and designs to restore connectivity temporarily 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 scaled at-sea integrated demonstrations of increasing complexity. Program technologies will transition to the Services. ***FY 2019 Plans:*** - Revise and update component and system architectures for final at-sea testing based on results of FY2018 integration and at-sea testing. - Complete integration for updated system and perform at-sea networking demonstration. - Evaluate hardware packaging and radio deployment options in support of potential configuration modifications. - Analyze data collected and finalize reports on Tactical Undersea Network Architecture experimentation and demonstration events. - Transition interface, control, and system architecture documentation to the Services. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Title: Tactical Exploitation of the Acoustic Channel (TEAC)	12.270	7.699	-
Description: The Tactical Exploitation of the Acoustic Channel (TEAC) program will provide the capability to coherently combine acoustic energy from a distributed network of underwater acoustic sources to improve signal transmission in an undersea environment. The ability to cohere multiple underwater sensors will have a transformative impact on a number of compelling applications including surveillance, communications, and vehicle positioning. For all of these applications, sensor gain is currently achieved by deploying large, costly, and cumbersome cabled arrays. The TEAC program will create the opportunity to deploy groups of low unit-cost sources that work cooperatively to focus energy undersea. This provides an extensible, affordable, and flexible method to harness the rapid development of undersea vehicles and new acoustic source technologies. Technologies developed under this program are intended to transition to the Navy. ***FY 2019 Plans:*** - Demonstrate and test at-sea cohering of acoustic sources. - Analyze sea-test data to identify system performance robustness. - Begin development of command and control for a semi-autonomous distributed system.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Develop concept of operations for TEAC system deployment. - Test motion mitigation algorithms and command and control methods and demonstrate results in a limited test. - Develop mobile source network, algorithms, and signal waveforms for at-sea demonstration of semi-autonomous distributed system. - Develop test plan, system architecture, and acoustic propagation modeling for final at-sea demonstration. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
Title: Hydra ***Description:*** The Hydra program developed and demonstrated advanced capabilities for the undersea deployment and employment of unique payloads. Hydra integrated existing and emerging technologies and the ability to be positioned in the littoral undersea battlespace to create a disruptive capability. The system consisted of a modular enclosure with communications, command and control, energy storage, and standard interfaces for payload systems. The modular enclosures were deployed by various means, depending on the need for speed and stealth, and remain deployed until awakened for employment. Hydra developed critical enabling technologies for energy storage and recharging, communications, command and control, deployment, and autonomous operations. Technology developed under this program is transitioned to the Navy.	7.558	-	-
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 provided 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 addressed included, 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 leveraged Navy connectivity, autonomy, guidance, navigation, and obstacle avoidance technologies. Under an existing Memorandum of Agreement, following vehicle integration and initial testing, the program is transitioning to the Navy.	4.500	-	-
Title: Hybrid Multi Material Rotor Full Scale Demonstration (HyDem)	3.000	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
Description: The Hybrid Multi Material Rotor Full Scale Demonstration (HyDem) program applied breakthroughs in materials and material system technologies, and multi-disciplinary design methods to a Virginia Class submarine propulsor, a critical component in submarine performance. This new propulsor enabled the Navy to operate its submarine fleet with improved capability, allowing for the creation of strategic surprise. Submarines can exploit expanded areas 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 Navy has evaluated 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 Columbia Class submarines, and could back-fit previously constructed Virginia Class submarines. Technology developed under this program has transitioned to the Navy.			
Accomplishments/Planned Programs Subtotals	123.462	110.363	132.484

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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
NET-06: *NETWORK-CENTRIC WARFARE TECHNOLOGY*	-	230.769	223.743	280.453	-	280.453	178.448	88.886	44.000	10.000	-	-

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 2018	FY 2019	FY 2020
Title: Classified DARPA Program	230.769	223.743	280.453
Description: This project funds Classified DARPA Programs. Details of this submission are classified. ***FY 2019 Plans:*** Details will be provided under separate cover. ***FY 2020 Plans:*** Details will be provided under separate cover. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** Details will be provided under separate cover.			
Accomplishments/Planned Programs Subtotals	230.769	223.743	280.453

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 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 3: *Advanced Technology Development (ATD)*	**R-1 Program Element (Number/Name)** PE 0603767E / *SENSOR TECHNOLOGY*

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	202.189	183.101	163.903	-	163.903	269.619	238.758	263.964	269.964	-	-
SEN-01: *SURVEILLANCE AND COUNTERMEASURES TECHNOLOGY*	-	32.964	47.422	40.551	-	40.551	31.281	22.208	8.401	8.401	-	-
SEN-02: *SENSORS AND PROCESSING SYSTEMS*	-	85.347	63.562	69.452	-	69.452	206.978	202.357	251.599	261.563	-	-
SEN-06: *SENSOR TECHNOLOGY*	-	83.878	72.117	53.900	-	53.900	31.360	14.193	3.964	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 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.

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.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 3: *Advanced Technology Development (ATD)*	**R-1 Program Element (Number/Name)** PE 0603767E / *SENSOR TECHNOLOGY*

B. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	210.123	190.128	272.997	-	272.997
Current President's Budget	202.189	183.101	163.903	-	163.903
Total Adjustments	-7.934	-7.027	-109.094	-	-109.094
• Congressional General Reductions	0.000	-7.027			
• 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	-1.839	0.000			
• SBIR/STTR Transfer	-6.095	0.000			
• TotalOtherAdjustments	-	-	-109.094	-	-109.094

Change Summary Explanation

FY 2018: Decrease reflects SBIR/STTR transfer and reprogrammings.

FY 2019: Decrease reflects Congressional reduction.

FY 2020: Decrease reflects rephasing of several programs in the Surveillance and Countermeasures Technology and Sensors and Processing Systems projects and classified program reduction.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / *SENSOR TECHNOLOGY*	Project (Number/Name) SEN-01 / *SURVEILLANCE AND COUNTERMEASURES TECHNOLOGY*	

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
SEN-01: *SURVEILLANCE AND COUNTERMEASURES TECHNOLOGY*	-	32.964	47.422	40.551	-	40.551	31.281	22.208	8.401	8.401	-	-

A. Mission Description and Budget Item Justification

The Surveillance and Countermeasures Technology 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 2018	FY 2019	FY 2020
Title: Aerial Dragnet	15.501	23.508	11.856

Description: Aerial Dragnet seeks to detect multiple small Unmanned Aerial Systems (UAS) in complex and/or urban terrain before they are within Line-Of-Sight (LOS) of friendly assets. Unlike traditional air targets, small UASs pose a special threat in urban terrain for several reasons: they can fly at low altitudes between buildings, they are small making them difficult to sense, and they move at slow speeds making them difficult to differentiate from other moving objects. Moreover, the development of small UASs is driven by commercial technologies, which make them rapidly adaptable and very easy to use. Building upon research conducted in the System of Systems Integration Technology and Experimentation (SoSITE) program (budgeted in PE 0603766E, Project NET-01), Aerial Dragnet will perform surveillance using an architecture consisting of networked sensors mounted on distributed aerial platforms. The ability to see over and into urban terrain allows an Aerial Dragnet to detect, track, and classify UAS incursions rapidly, thus enabling multiple defeat options. This program focuses on the development of payloads to be hosted on unmanned aerial platforms, comprising of signal processing software, sensor hardware, and networking for distributed, autonomous operation. The system will be scalable to provide cost-effective surveillance coverage from neighborhood to city-sized areas. Aerial Dragnet technologies are expected to transition to the Army, Marine Corps, and Department of Homeland Security.

FY 2019 Plans:

- Update hardware sensor payloads to reduce size, weight, power, and cost.
- Extend software to enable target tracking non-line-of-sight from sensor platform.
- Develop autonomy algorithms to allow surveillance platforms to adapt to urban terrain.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Demonstrate and test the performance of the system in a multi-neighborhood-sized urban area. ***FY 2020 Plans:*** - Develop software interfaces relating to existing transition partners command and control architectures and Programs of Record. - Develop algorithms and software interfaces to integrate with existing and fielded sensor systems for transition cooperation. - Demonstrate and test the performance of the system in a robust urban environment with input on transition partner challenges. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects the focus on integration with fielded systems and finalizing of sensor development.			
Title: Shosty ***Description:*** Shosty seeks to develop and demonstrate enhanced capabilities for high frequency (HF) over-the-horizon-radar (OTHR) systems. This program will develop techniques to characterize distributed skywave HF radar propagation channels and measure radar backscatter from the surface. System signal processing, modeling, analysis, and over-the-air experimentation will be conducted to assess performance. Technologies developed under the Shosty program will transition to the Services. ***FY 2019 Plans:*** - Begin design and integration of multi-channel receive systems. - Begin development of waveforms and signal processing for distributed geometries. - Perform system modeling to assess target detection performance. ***FY 2020 Plans:*** - Complete HF transmit system integration. - Conduct over-the-air field tests to assess propagation and backscatter characteristics. - Confirm physical modeling and analysis using measured experimental data. - Compare performance of distributed geometries through modeling and experimentation. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The increase in FY 2020 reflects the shift from system development to field testing and demonstrations.	6.774	14.500	15.268
Title: All Source Combat Operations and Targeting (ASCOT) ***Description:*** The All Source Combat Operations and Targeting (ASCOT) program will allow maritime platforms to maintain robust battlespace awareness and survivability by combining data and coordinating operations using all available sensors. The program will create methods for optimal balancing of battlespace awareness and survivability by leveraging existing networked sensor and local platform sensors. The program builds upon technology developed as a part of the Resilient Synchronized Planning & Assessment Contested Environment (RSPACE) program, budgeted in PE 0603766E/Project NET-01. Key attributes	-	9.414	13.427

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
of this program are survivability, information latency, reliability, and endurance. Demonstrations on relevant platforms in relevant environments will be used to validate the technology. Technologies from this program will transition to the Services. ***FY 2019 Plans:*** - Initiate the development of sensor fusion and data analysis tools. - Initiate the development of payloads for networked sensor testing. ***FY 2020 Plans:*** - Conduct testing of sensor fusion and data analysis tools in simulation and test environment. - Analyze collected data to identify system performance and examine robustness. - Conduct lab testing of payload designs. - Initiate the development of adaptive combat control techniques. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects the initiation of system integration and major testing and demonstration efforts in FY 2020.			
Title: Multi-Optical Sensing (MOS) ***Description:*** 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 enabled 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 leveraged emerging high-sensitivity Focal Plane Array (FPA) and compact, multi-band laser systems technology in the near/mid/long-wave infrared bands to enable the development of a multi-optical sensing system. Technical challenges included the demonstration of inexpensive, multi-band, large-format, photon-counting, high-bandwidth receivers and their integration into a multi-optical sensor suite compatible with airborne assets. The MOS program advanced 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 transitioned to the Air Force.	10.689	-	-
Accomplishments/Planned Programs Subtotals	32.964	47.422	40.551

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 3	**R-1 Program Element (Number/Name)** PE 0603767E / *SENSOR TECHNOLOGY*	**Project (Number/Name)** SEN-01 / *SURVEILLANCE AND COUNTERMEASURES TECHNOLOGY*

E. Performance Metrics

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

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / *SENSOR TECHNOLOGY*	Project (Number/Name) SEN-02 / *SENSORS AND PROCESSING SYSTEMS*	

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
SEN-02: *SENSORS AND PROCESSING SYSTEMS*	-	85.347	63.562	69.452	-	69.452	206.978	202.357	251.599	261.563	-	-

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 2018	FY 2019	FY 2020
Title: Seeker Cost Transformation (SECTR)	11.064	5.133	4.195
Description: 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) be very small size and weight and potentially low cost. SECTR-developed systems and technologies will be small size, weight and power (SWaP), low recurring cost, and be applicable to a wide range of weapons and missions, such as small unit lethality, suppression of enemy air defenses, precision strike, and strike of time-sensitive targets. Hardware technology will leverage 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. SECTR 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 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 2019 Plans: - Conduct prototype SECTR seeker and precision guided munition (PGM) captive-carry flight tests and hardware-in-the-loop (HWIL) tests. - Complete HWIL algorithm assessment.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Conduct free-flight test of integrated prototype SECTR seeker-guided PGM. ***FY 2020 Plans:*** - Conduct additional free-flight tests of SECTR prototype seeker. - Assess seeker performance and update HWIL models and assumptions as needed. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects a shift from prototype development and captive carry to free-flight testing and performance verification.			
Title: Small Satellite Sensors	26.651	18.456	14.058
Description: The Small Satellite Sensors program will develop and space-qualify Electro-Optical Infrared (EO/IR) sensor and inter-satellite communications technologies and establish feasibility for new DoD tactical capabilities to be implemented on small (< 100 kg) 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 Services. ***FY 2019 Plans:*** - Launch satellites and conduct on-orbit operations, including mission planning, payload testing, and image collection. - Downlink raw imagery for ground processing and pre-processed imagery for comparative analysis. - Perform data collection campaigns and analyze experimental data from satellites. - Perform inter-satellite communications link tests and coordinate multi-satellite operations. - Demonstrate feasibility of novel real-time tactical operational concepts. ***FY 2020 Plans:*** - Complete space-based data collections. - Complete user demonstration and field activities. - Develop models and reports which quantify effectiveness of the sensor technology and the suite of processing algorithms.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
- Transition key results and technologies to military users for use in operational constellations. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects changes in the on-orbit operations plans to align better with available launch dates.			
Title: Dynamically Composed RF Systems ***Description:*** Dominance of the Radio Frequency (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. 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 airframe integration and the associated wide-band agile electronics to support converged missions over those apertures; (3) a heterogeneous signal processing complex implementing hardware-agnostic RF operating modes (the RF Virtual Machine); (4) software tools for the control, coordination, and scheduling of RF functions and payloads at the element level to maximize overall task performance (a System and Sensor Resource Manager (SSRM)). This capability can be adapted to address diverse missions. Technology developed under this program will transition to the Services. ***FY 2019 Plans:*** - Initiate collaboration to support transition opportunities and develop approaches for integrating SSRM onto existing RF payloads. - Complete interface control documents defining interfaces between the SSRM, the payload, and off-board controllers. - Design and begin implementation of initial version of objective system SSRM software. ***FY 2020 Plans:*** - Complete initial version of objective system SSRM software and payload interfaces. - Integrate SSRM software onto third-party payload and conduct integration testing to validate ability of SSRM to control the third party payload. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects increased program focus on SSRM application to existing RF payloads.	16.356	11.067	9.892
Title: All-Signal Tactical Real-Time Analyzer (ASTRAL) ***Description:*** The All-Signal Tactical Real-time Analyzer (ASTRAL) program will develop and demonstrate a system for radio frequency and optical electromagnetic signal surveillance and environment understanding. Building on technologies explored under the Dynamically Composed RF Systems program, also budgeted in this PE/Project, the objective of ASTRAL is to provide	4.680	12.190	11.832

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
a factor of at least 1000 times improvement over current signal awareness processing speed over broad spectral coverage. The program will use technology that supports a development path leading to a mobile, tactical capability. The development objectives of the ASTRAL program are to (1) develop a hybrid processor that provides real-time processing of the most challenging Low-Probability-of-Intercept (LPI) threat signals across a wide bandwidth, and (2) identify exploitation algorithms for military applications that are well-suited to this type of hybrid processor. Several strategic and tactical spectrum awareness applications that may be addressed include but are not limited to (a) real-time exploitation of optical communications, (b) city-wide wireless device geo-location, (c) broadband LPI radar warning, and (d) theater-wide spread-spectrum LPI radio geo-location. ASTRAL will transition to the Services and Intelligence Community. ***FY 2019 Plans:*** - Identify hybrid processor architectures suited for a wide range of tactical military signal awareness applications. - Integrate the brassboard hybrid signal processor system. - Demonstrate LPI signal processing at broad bandwidth in a laboratory environment with simulated and real signal inputs. - Select hybrid processor architectures for specific tactical military application development. ***FY 2020 Plans:*** - Begin hybrid processor architecture development, identifying risks and risk mitigation approaches. - Demonstrate execution of algorithms suitable for tactical applications with brassboard system in the laboratory environment. - Define concept of operations plans for tactical applications of the hybrid processor architectures. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects minor program repricing.			
Title: Collection and Monitoring via Planning for Active Situational Scenarios (COMPASS)*	-	10.458	19.153
Description: *formerly Cognitive Maneuver The Collection and Monitoring via Planning for Active Situational Scenarios (COMPASS) program will build decision aids for gray zone scenarios, where adversaries attempt to manipulate a U.S.-allied nation through the use of both kinetic and non-kinetic means. Based on research performed under the Resilient Synchronized Planning & Assessment Contested Environment (RSPACE) program, budgeted in PE 0603766E, Project NET-01, the purpose of the COMPASS program is to reduce ambiguity and reveal intent of gray zone actors who use techniques such as misinformation and intimidation to destabilize host nations and possibly produce advantageous conditions for military engagements. The tools produced by COMPASS will automate gray zone information operations and help U.S. forces adapt to changing conditions and adversary responses. Instead of relying on passive collection of sensory data, COMPASS will employ active sensing and recommend actions that U.S. Forces and allied partners can take to stimulate the environment and reveal any hostile strategies. To achieve this goal, COMPASS will build and			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
demonstrate tools to 1) develop a dynamic model of hostile activities in a gray zone environment, 2) assess the decision space to recommend which actions may provide the highest value information, and 3) monitor execution of these actions to assess incremental progress toward reducing the ambiguity of the operating environment and suggest adjustments. COMPASS will transition to the Services. ***FY 2019 Plans:*** - Develop a taxonomy for COMPASS operations. - Design gray zone modeling, initial algorithms for action generation, and initial development of monitor and assessment tools. - Build a library of real and synthetic data and a laboratory simulation test environment. - Commence development of technology to create a situational awareness picture when critical services of the operating environment are disrupted. ***FY 2020 Plans:*** - Increase complexity of the gray zone environment and improve the effectiveness of the algorithms for action generation. - Expand situational awareness to include social activities such as economic, political, and influence campaigns. - Improve the functionality of the tool to account for adversaries that adapt their behavior. - Conduct demonstrations for operational users to assess utility and explore transition. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects increased modeling efforts and increased demonstrations with operational users.			
Title: Cross-Domain Multi-Modality Sensing & Targeting	-	-	10.322
Description: The Cross-Domain Multi-Modality Sensing & Targeting program will develop sensors and exploitation techniques capable of performing wide-area search to detect high-value targets in order to task engagement systems to close effects-chains. Finding and prosecuting targets with distributed effects chains requires the ability to detect, track, and maintain custody of targets across sensors with different modalities residing in various domains. Building upon technologies from the Automatic Target Recognition (ATR) program, budgeted in this PE/Project, this program will examine both the sensors and the exploitation needed to perform this wide area search for missions in denied territories and maintain positive chain of custody hand-offs to one or more targeting sensors. The sensors developed under this program will concentrate on sensor modalities that are mostly geometry-invariant and have the potential to be used in highly proliferated systems, such as small satellite constellations and small terrestrial platforms (e.g. class-I or II unmanned aerial system). The exploitation portion of this program will develop algorithms to ensure consistency when passing chain of custody between sensors in different domains with possibly different sensing modalities and will also be designed to increase confidence and accuracy as targets are passed between sensors. Technology developed by this program will transition to the Services and other government agencies.			

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
FY 2020 Plans: - Begin development of exploitation algorithms suitable for abstracted target characterization to enable consistent chain of custody. - Begin development of multi-mode sensor modules. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects program initiation.			
Title: Spatial, Temporal and Orientation Information for Contested Environments (STOIC) ***Description:*** 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, achieved 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 2019 Plans:*** - Conduct field demonstrations of Very Low Frequency (VLF)-based positioning system with ionospheric modeling correction to validate performance in a relevant environment. - Conduct evaluation and analysis of field test results. - Transition VLF-based positioning system to Army and Navy acquisition programs. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.	10.457	3.189	-
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 provide only limited, static mission support due to pre-programmed target lists and operating modes. 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 operational limitations while also providing significant performance improvements, dramatically reduced development times, and reduced life-cycle maintenance costs. Recent breakthroughs in deep learning algorithms and embedded computing systems offer promise for dramatic improvements in ATR utility. The program will focus on three core areas: (1) development of on-line adaptive algorithms that enable performance-driven sensing and ATR utility; (2) algorithm training	10.639	3.069	-

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
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 2018	FY 2019	FY 2020
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 demands of ATR systems. ATR technology developed under the program is planned for transition to the Services. ***FY 2019 Plans:*** - Continue ATR algorithm development with the focus on significantly reducing training data requirements. - Conduct additional flight demonstrations of ATR algorithms operating on an airborne platform to facilitate transition to the Services. - Extend ATR applications to the National Geospatial Intelligence Agency (NGA) Scale cloud computing environment and other Intelligence Surveillance Reconnaissance (ISR) systems. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects program completion.			
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 developed a real-time spotlight Synthetic Aperture Radar (SAR) imaging sensor that provides imagery of a region to allow high-resolution fire direction in conditions where optical sensors do not function. Technology from this program transitioned to the Special Operations Command (SOCOM).	2.300	-	-
Title: Adaptive Radar Countermeasures (ARC) ***Description:*** The Adaptive Radar Countermeasures (ARC) program developed new algorithms for rapidly protecting DoD systems against new or unknown radar-based threats. Protecting these systems currently relies on uniquely identifying an enemy radar and applying an appropriate, pre-programmed Electronic Countermeasure (ECM), which can take years to develop. The emergence of digitally-programmed radars that exhibit novel behaviors and agile waveform characteristics, however, has made this approach to countering radar-based threats increasingly challenging. Developing new ECM over several years is no longer sufficient. ARC developed new processing techniques and algorithms that adapt in real-time to generate suitable countermeasures. The program transitioned to Air Force, Navy, and Marine Corps airborne electronic warfare systems.	3.200	-	-
Accomplishments/Planned Programs Subtotals	85.347	63.562	69.452

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency		Date: March 2019
Appropriation/Budget Activity 0400 / 3	**R-1 Program Element (Number/Name)** PE 0603767E / *SENSOR TECHNOLOGY*	**Project (Number/Name)** SEN-02 / *SENSORS AND PROCESSING SYSTEMS*

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.

Exhibit R-2A, RDT&E Project Justification: PB 2020 Defense Advanced Research Projects Agency			Date: March 2019
Appropriation/Budget Activity 0400 / 3	R-1 Program Element (Number/Name) PE 0603767E / *SENSOR TECHNOLOGY*	Project (Number/Name) SEN-06 / *SENSOR TECHNOLOGY*	

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
SEN-06: *SENSOR TECHNOLOGY*	-	83.878	72.117	53.900	-	53.900	31.360	14.193	3.964	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 2018	FY 2019	FY 2020
Title: Classified DARPA Program	83.878	72.117	53.900
Description: This project funds Classified DARPA Programs. Details of this submission are classified. ***FY 2019 Plans:*** Details will be provided under separate cover. ***FY 2020 Plans:*** Details will be provided under separate cover. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** Details will be provided under separate cover.			
Accomplishments/Planned Programs Subtotals	83.878	72.117	53.900

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 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 6: *RDT&E Management Support*	**R-1 Program Element (Number/Name)** PE 0605001E / *MISSION SUPPORT*

COST ($ in Millions)	Prior Years	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	64.269	65.646	68.498	-	68.498	69.318	69.882	70.710	71.556	-	-
MST-01: *MISSION SUPPORT*	-	64.269	65.646	68.498	-	68.498	69.318	69.882	70.710	71.556	-	-
Quantity of RDT&E Articles	-	-	-	-	-	-	-	-	-	-		

A. Mission Description and Budget Item Justification

The Mission Support Program Element 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.

B. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	63.769	65.646	66.152	-	66.152
Current President's Budget	64.269	65.646	68.498	-	68.498
Total Adjustments	0.500	0.000	2.346	-	2.346
• 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	0.500	0.000			
• SBIR/STTR Transfer	0.000	0.000			
• TotalOtherAdjustments	-	-	2.346	-	2.346

Change Summary Explanation

FY 2018: Increase reflects reprogrammings.
FY 2019: N/A
FY 2020: Increase reflects minor repricing.

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Mission Support	64.269	65.646	68.498
Description: Mission Support			
FY 2019 Plans:			

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 6: *RDT&E Management Support*	**R-1 Program Element (Number/Name)** PE 0605001E / *MISSION SUPPORT*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
- 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. ***FY 2020 Plans:*** - 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. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 increase reflects increased costs associated with rent, security, infrastructure support, and civilian personnel costs.			
Accomplishments/Planned Programs Subtotals	64.269	65.646	68.498

D. Other Program Funding Summary ($ in Millions)

N/A

Remarks

E. Acquisition Strategy

N/A

F. Performance Metrics

N/A

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	100.804	0.000	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-
SB-01: *SMALL BUSINESS INNOVATION RESEARCH*	-	100.804	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: 115-232 (National Defense Authorization Act 2019) and the Small Business Act (15 U.S.C. 638), 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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	0.000	0.000	0.000	-	0.000
Current President's Budget	100.804	0.000	0.000	-	0.000
Total Adjustments	100.804	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	100.804	0.000			

Change Summary Explanation

FY 2018: Increase reflects the SBIR/STTR transfer.
FY 2019: N/A
FY 2020: N/A

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Small Business Innovation Research	100.804	-	-
Description: The 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-			

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
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.			
Accomplishments/Planned Programs Subtotals	100.804	-	-

D. Other Program Funding Summary ($ in Millions)

N/A

Remarks

E. Acquisition Strategy

N/A

F. Performance Metrics

Not applicable.

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
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 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total	FY 2021	FY 2022	FY 2023	FY 2024	Cost To Complete	Total Cost
Total Program Element	-	14.017	13.643	13.208	-	13.208	13.268	13.343	13.340	13.416	-	-
MH-01: *MANAGEMENT HQ - R&D*	-	14.017	13.643	13.208	-	13.208	13.268	13.343	13.340	13.416	-	-
Quantity of RDT&E Articles	-	-	-	-	-	-	-	-	-	-		

A. Mission Description and Budget Item Justification

The Management HQ - R&D Program Element provides funding for the administrative support costs of the Defense Advanced Research Projects Agency. This project provides funding for DARPA Management Headquarters Activities (MHA). The funds provide personnel compensation for management headquarters civilians as well as associated travel and support contract costs. Departmental Service Requirements Review Board (SRRB) reductions were taken in this PE. Mission support costs are reflected in PE 0605001E, Project MST-01.

B. Program Change Summary ($ in Millions)	FY 2018	FY 2019	FY 2020 Base	FY 2020 OCO	FY 2020 Total
Previous President's Budget	14.017	13.643	13.498	-	13.498
Current President's Budget	14.017	13.643	13.208	-	13.208
Total Adjustments	0.000	0.000	-0.290	-	-0.290
• 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	-	-	-0.290	-	-0.290

Change Summary Explanation

FY 2018: N/A

FY 2019: N/A

FY 2020: Decrease reflects minor repricing.

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
Title: Management Headquarters	14.017	13.643	13.208
Description: Management Headquarters			

Exhibit R-2, RDT&E Budget Item Justification: PB 2020 Defense Advanced Research Projects Agency	Date: March 2019
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide I* BA 6: *RDT&E Management Support*	**R-1 Program Element (Number/Name)** PE 0605898E *I MANAGEMENT HQ - R&D*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2018	FY 2019	FY 2020
FY 2019 Plans: - Fund management headquarters civilian salaries, benefits, travel and support contract costs. ***FY 2020 Plans:*** - Fund management headquarters civilian salaries, benefits, travel and support contract costs. ***FY 2019 to FY 2020 Increase/Decrease Statement:*** The FY 2020 decrease reflects minor repricing.			
Accomplishments/Planned Programs Subtotals	14.017	13.643	13.208

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.