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S. HRG. 114–658, PT. 5

DEPARTMENT OF DEFENSE AUTHORIZATION FOR APPROPRIATIONS FOR FISCAL YEAR 2017 AND THE FUTURE YEARS DEFENSE PROGRAM

HEARING

BEFORE THE

SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES

OF THE

COMMITTEE ON ARMED SERVICES
UNITED STATES SENATE

ONE HUNDRED FOURTEENTH CONGRESS

SECOND SESSION

ON

S. 2943

TO AUTHORIZE APPROPRIATIONS FOR FISCAL YEAR 2017 FOR MILITARY ACTIVITIES OF THE DEPARTMENT OF DEFENSE, FOR MILITARY CONSTRUCTION, AND FOR DEFENSE ACTIVITIES OF THE DEPARTMENT OF ENERGY, TO PRESCRIBE MILITARY PERSONNEL STRENGTHS FOR SUCH FISCAL YEAR, AND FOR OTHER PURPOSES

PART 5
EMERGING THREATS AND CAPABILITIES

APRIL 12, 2016

Printed for the use of the Committee on Armed Services

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Available via the World Wide Web: http://www.fdsys.gov/

U.S. GOVERNMENT PUBLISHING OFFICE

25–921 PDF WASHINGTON : 2017

For sale by the Superintendent of Documents, U.S. Government Publishing Office
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APRIL 12, 2016

DEPARTMENT OF DEFENSE AUTHORIZATION FOR APPROPRIATIONS FOR FISCAL YEAR 2017 AND THE FUTURE YEARS DEFENSE PROGRAM

TUESDAY, APRIL 12, 2016

U.S. SENATE,
SUBCOMMITTEE ON EMERGING
THREATS AND CAPABILITIES,
COMMITTEE ON ARMED SERVICES,
Washington, DC.

THE STRATEGY AND IMPLEMENTATION OF THE DEPARTMENT OF DEFENSE'S TECHNOLOGY OFFSETS INITIATIVE

The subcommittee met, pursuant to notice, at 2:36 p.m. in Room SR–222, Russell Senate Office Building, Senator Deb Fischer (chairwoman of the subcommittee) presiding.

Members present: Senators Fischer, Cotton, Tillis, Nelson, Manchin, Kaine, and Heinrich.

OPENING STATEMENT OF SENATOR DEB FISCHER, CHAIRWOMAN

Senator FISCHER. Good afternoon. The Subcommittee on Emerging Threats and Capabilities meets today to receive testimony on the Department of Defense's third offset strategy.

In 2014, Under Secretary Kendall provided this subcommittee with a classified briefing on U.S. technological superiority. In November of that year, then-Secretary of Defense Hagel announced the start of what he referred to as, quote, "a game-changing third offset strategy," end quote.

Since this announcement, many senior leaders in the Department of Defense, including Secretary and Deputy Secretary, have spoken at length about our military's eroding technological edge and the significance of the third offset strategy. However, these discussions tend to broadly focus on abstract ideas and the general importance of innovation. The purpose of today's hearing is to explore the concrete details beneath the notional concepts.

I look forward to hearing from our witnesses today about what activities make up the third offset strategy and the extent to which it represents a change from past practice.

Appearing before the subcommittee today, we have Dr. Roper, Director of the Strategic Capabilities Office; Dr. Prabhakar, Director of the Defense Advanced Research Projects Agency, or DARPA;

and Secretary Stephen Welby, the Assistant Secretary of Defense for Research and Engineering.

I'd like to welcome and thank you all for being here today.

I would turn to my Ranking Member for any opening comments he would like to make.

STATEMENT OF SENATOR BILL NELSON

Senator NELSON. Madam Chairman, thank you.

I simply am a big fan of what these folks do. I think we need to support the President's request, and then double it.

[Laughter.]

Senator NELSON. That's my opening statement.

Senator FISCHER. Thank you, Senator Nelson.

We will now turn to our witnesses. Your full statements will be made part of the record, and I would ask that you provide us with some brief opening comments, after which we will proceed to 7-minute rounds in our questioning.

Secretary Welby.

STATEMENT OF HONORABLE STEPHEN P. WELBY, ASSISTANT SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING

Mr. WELBY. Chairman Fischer, Ranking Member Nelson, members of the committee, Senator Heinrich, thank you. I'm pleased to have the opportunity to provide testimony on the technological underpinnings of the Department of Defense's third offset strategy. I join my colleagues from DARPA and the Strategic Capabilities Office in doing so.

In my role as Assistant Secretary of Defense for Research and Engineering, I serve as the Chief Technology Officer for the Department of Defense, and I'm responsible for the Department's strategies and supporting plans to develop and leverage technology needed to support continued U.S. technological superiority.

For the last 30 years, the U.S. and our allies have had—been able to count on a set of unique capabilities in combat that no regional adversary could bring to bear. We're now at a pivotal moment in history, where the advanced technical capability and capacity that the Nation has relied upon on the battlefield is now being challenged by military technology investments being made by increasingly capable and assertive powers. As Secretary Carter said during his budget rollout testimony, Russia and China are our most stressing competitors. They have developed and continue to advance military systems that threaten our advantages in specific areas. In some cases, they're developing new weapons and ways of war that seek to achieve their objectives rapidly before they hope we can respond.

Our Nation has long pursued strategies that leverage U.S. technological advantage as a force multiplier. We need to continue to leverage those advances in technology and in new operational concepts to provide sustained advantage to U.S. forces, shifting the landscape of future national security competition to our advantage by seeking asymmetric opportunities in technological and operational innovation.

Merriam-Webster defines an "offset" as something that serves to counterbalance or compensate for something else. An offset strat-

egy is an approach to military competition that seeks to provide an asymmetric advantage to the United States rather than competing head-to-head or tank-for-tank or plane-for-plane in an area where a potential adversary may also possess potential strength. Instead, an offset strategy seeks to shift the axis of competition through the introduction of new operational concepts and technologies towards one in which the U.S. has a significant and sustainable advantage.

The U.S. was successful in pursuing two distinct offset strategies during the Cold War:

The first of these offset strategies occurred in the 1950s, when President Eisenhower sought to overcome the Warsaw Pact's numerical advantage by leveraging U.S. nuclear superiority to introduce battlefield nuclear weapons, which shifted the axis of competition from competing on conventional force numbers to competing in an area where the U.S. had an advantage.

A second offset strategy occurred in the 1980s, with the recognition that the Soviet Union had achieved nuclear power—the United States. The second offset strategy sought to create an enduring advantage by pursuing a brand new approach to joint operations, leveraging the combined effects of near-zero-miss distance weapons, realtime targeting, and joint battle networks to create a new era of conventional precision engagement.

This combined suite of technologies gave the U.S. a fundamental advantage that we have sustained for the last 30 years, capabilities that provided the U.S. and its allies with an asymmetrical advantage in every fight. Today, we see the emergence of increasing technological symmetry, and that's why the Department is discussing the need for a new offset strategy.

Today, the third offset strategy is not a document that you can go find in a drawer somewhere in the Pentagon. Instead, it—the term really describes the broad nature of capabilities that the Department expects to realize over the coming years by pursuing developments in advanced technologies, by conducting experimentation with prototype systems, through increased emphasis on wargaming to help us understand new concepts, and by emphasizing the need to innovate across the entire DOD enterprise.

In the fiscal 2017 defense budget request, Secretary Carter identified more than $3.6 billion of investment in fiscal year–2017 and 18 billion in specific investment over the Future Year Defense Plan, focused on spurring research, development, and procurement of advanced capabilities that our military will need to fight and win in high-end conflicts in the future. These investments and others directly support and enable a third offset strategy.

The investments in the fiscal 2017 defense budget request include new capabilities that can be fielded rapidly through modifying and upgrading existing systems—and we'll be happy to talk about some of those here today; material concepts that could enter accelerated development; and, again, something I'd like to talk about, our technology-driven concepts that could have a significant impact on the joint force over a longer term. They—the investments also emphasized the critical importance of focusing on the cost of weapon systems so that—to be able to introduce these kind of disruptive capabilities into the joint force at real scale.

Deputy Secretary of Defense Work has emphasized, in his remarks, the importance of advanced software-enabled capabilities for a third offset. Emerging capabilities in advanced algorithms and software intelligence offer a significant potential advantage to a joint force, enabling systems to process large quantities of data at a high speed to identify emergent patterns and trends, speeding decision making and enabling faster-than-human reaction time in new and emerging areas of conflicts, such as cyber and electronic warfare, and supporting new models of manned-unmanned combat teaming; and finally, permitting new weapons concepts that can operate in critically challenging cyber and electronic warfare-constrained environments.

The Department's goal to sustain and advance our Nation's technological superiority for the 21st century national security environment requires a sound research-and-development investment strategy. The DOD's research and engineering community works to create options for the Department and serves as a novel and agile innovation engine for the Department. The core science and technology efforts of ASDR&E, the service laboratories of DARPA and SCO are focused on creating long-range opportunities for the Department's future material options.

As DOD develops the third offset strategy, the Department's research and engineering enterprise is well prepared to develop, shape, and create technology options to inform future operational concepts. Our goal must always be to ensure that our soldiers, sailors, airmen, and marines always have the scientific knowledge, the decisive technology, the advanced systems and tools, and the materiel edge to succeed when called upon. Our research and engineering enterprise measures its success in the security of the Nation and the success of our warfighters.

Let me close by thanking the committee for its strong interest in and support of the Department's research and engineering efforts as we work to discover, design, and deliver the technology capabilities our warfighters will need in the future.

Thank you.

[The prepared statement of Mr. Welby follows:]

PREPARED STATEMENT BY MR. STEPHEN WELBY

INTRODUCTION

Chairman Fischer, Ranking Member Nelson, and Members of the Subcommittee, I am pleased to have the opportunity to provide testimony on the Department of Defense's Third Offset Strategy and to join my colleagues from Defense Advanced Research Projects Agency (DARPA) and Strategic Capabilities Office (SCO). In my role as the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)), the Chief Technology Officer of the Department of Defense, I am responsible for the Department's strategies and supporting plans to develop and leverage the technologies needed to ensure continued US technological superiority.

We are at a pivotal moment in history where the advanced technical capability and capacity that the Nation has relied upon to provide us with unmatched technological superiority on the battlefield (including capabilities in precision weapons, long-range ISR, space systems and stealth) are now being challenged by the military technology investments being made by increasingly capable and assertive powers. Other nations are increasing their investments in advanced capabilities, including anti-access/area-denial capabilities, which are intended to counter US technological strengths and deter the US from projecting power abroad to defend our national interests, maintaining international norms, and supporting our allies and partners.

Our nation has long pursued strategies that leveraged US technological advantage as a force multiplier. We continue to leverage advances in technology and new operational concepts to provide sustained advantage to US forces—shifting the landscape of future national security competition to our advantage by seeking asymmetric opportunities in technological and operational innovation.

A FOCUS ON THE FUTURE

As the Department looks to the future, significant global challenges are on the horizon that will require renewed emphasis on sustaining US technological superiority. For the last 30 years the US and our allies have been able to count on a set of unique capabilities in combat that no regional adversary could bring to bear: long range precision weapons, airborne ISR for real time targeting, network centric integration of command and control, low observable systems, and integrated use of space assets. These technological capabilities enabled a US strategy of power projection—leveraging a limited forward presence with the ability to respond to provocation with follow-on forces that could be moved to theater and deployed with confidence in an opposed environment. Today, we are seeing a return to a more competitive environment—one where regional actors have studied US strengths and are capable of making the investments required to develop advanced systems designed to directly counter US technological strengths in a power projection environment. This evolution in our competitive technological posture will require the DOD to invest in the technological and operational innovations required to sustain our decisive conventional overmatch against regional adversaries.

As Secretary Carter has said, "Russia and China are our most stressing competitors. They have developed and are continuing to advance military systems that seek to threaten our advantages in specific areas. In some case, they are developing weapons and ways of wars that seek to achieve their objectives rapidly, before they hope, we can respond."[1] Given our constrained budget resources, we must pursue a technological strategy to ensure our conventional deterrence remains as strong in the future as it is today. Accomplishing this goal is one of the most important strategic tasks facing the Department.

As it has been in the past, technological and operational innovation will be the key to future strategy. Maintaining and extending our competitive, technological, and operational advantages is not a purely quantitative contest with other nations. Rather, the US must seek asymmetric advantages—particularly those that take advantage of US strengths in military and commercial technological innovation. We must accelerate our approaches to identifying promising technological differentiators, our processes for mapping technological capability to operational advantage, and our methods of moving new capabilities from laboratory to field.

Future capabilities will be increasingly joint in nature; leveraging the ability to synchronize simultaneous operations in the space, air, sea, undersea, ground, and cyber domains. Emerging tools based on breakthroughs in computer science, advanced electronics, novel communications and sensors, and human-machine interfaces will enable new operational concepts that will enable faster and better decision making, coordinated operations at range and across the battlespace by manned, unmanned, and cyber operations.

TOWARD A THIRD OFFSET STRATEGY

Merriam-Webster defines an Offset as "something that serves to counterbalance or to compensate for something else."[2] An offset strategy is an approach to military competition that seeks to asymmetrically compensate for a disadvantaged position. Rather than competing head to head in an area where a potential adversary may also possess significant strength, an offset strategy seeks to shift the axis of competition, through the introduction of new operational concepts and technologies, toward one in which the US has a significant and sustainable advantage. A successful offset strategy devalues an adversary's current advantages and imposes costs to react to US efforts and help establish a long-term competitive advantage for US forces.

The US was successful in pursuing two distinct offset strategies during the Cold War. These strategies enabled the US to "offset" the Soviet Union's numerical advantage in conventional forces without pursuing the enormous investments in forward deployed forces that would have been required to provide overmatch soldier for soldier and tank for tank. These offset strategies relied on fundamental innova-

[1] Remarks by Secretary Carter on the Budget at the Economic Club of Washington, DC, February 2, 2016

[2] http://www.merriam-webster.com/dictionary/offset

tion in technology, operational approaches, and organizational structure to compensate for Soviet advantage in time, space, and force size.

The first of these offset strategies occurred in the 1950's, when President Eisenhower sought to overcome Warsaw Pact's numerical advantage by leveraging US nuclear superiority to introduce battlefield nuclear weapons—thus shifting the axis of competition from conventional force numbers to an arena where the US possessed an asymmetrical advantage. This approach provided stability and offered the foundation for deterrence.

The second of these offset strategies arose in the late 1970's and 1980's with the recognition that the Soviet Union had achieved nuclear parity. The Second Offset Strategy, informed by studies such as the 1973 Long Range Research and Development Planning Program, sought to create an enduring advantage by pursuing a new approach to joint operations—leveraging the combined effects of conventional precision weapons, real-time long-range ISR sensor capabilities capable of supporting real time precision targeting, and the joint battle networks that permitted these capabilities to be synchronized and executed over the full breadth of the battlespace. These integrated systems-of-systems provided a significant force multiplier by improving the efficiency and effectiveness of conventional strike systems, creating opportunities for synergistic effects across warfighting domains, and permitting US forces to more effectively and rapidly project conventional power globally with reduced forward presence. These conventional targeting and strike capabilities built on US advantages in weapons technology, sensor technology, aviation systems, software and computer architecture, and space-based capabilities (particularly space based communications and the global positioning system) to provide the ability to service targets with unprecedented accuracy. This combined suite of technologies reflected unique US technical capabilities at the time—capabilities that provided the US and its allies with an asymmetric advantage over Soviet forces.

It is important to note that neither of these two original offset strategies was solely about technological advantage. In each case, it was the right combination of technology-enabled operational and organizational innovation that provided decisive strategic and operational advantage and therefore bolstered conventional deterrence.

The capabilities of the Second Offset Strategy provided the US with decisive conventional overmatch against regional adversaries. As a result, the asymmetric advantage provided by these capabilities has been a central feature of the US doctrine for over three decades.

WHAT HAS CHANGED?

At the time of the introduction of the Second Offset Strategy in the early 1980's, the US was the only nation with the knowledge and capacity to develop, deploy, and successfully execute the intelligence, surveillance and reconnaissance capabilities, the space-based systems, and the precision weapons that supported this approach. Today, competitors such as Russia and

China (and countries to which these nations proliferate advanced capabilities) are pursuing and deploying advanced weapons and capabilities that demonstrate many of the same technological strengths that provide the technological basis for US advantage. This growing symmetry between US technical capabilities and near-peer potential competitors is particularly seen in the capabilities demonstrated during Russian power-projection operations in Syria.

There has been significant public discussion about anti-access/area denial (A2/AD) capabilities. These advanced capabilities include anti-air and anti-surface sensors and weapons systems designed to make it more difficult for the US to project power and operate at extended range. Potential adversaries have had over two decades to study the tools and operational concepts that underpin the US technology-enabled conventional strategy and have learned from our operational successes. With the globalization of technology and technological talent and with growing resources being applied to military modernization, potential competitors are seeking similar technological capabilities to those the US has deployed, and are optimizing them to blunt US advantage. The emergence of A2/AD capabilities, which leverage similar precision guidance and seeker/sensor technologies to those that underpinned the Second Offset Strategy, again demonstrate the recent emergence of increased symmetry in military technical capabilities. Potential competitors are beginning to catch up, potentially eroding the margin of conventional advantage enjoyed by US forces since the end of the Cold War.

TOWARD A THIRD OFFSET STRATEGY

The emergence of increasing symmetry in national security environment suggests that it is again time to begin considering the mix of technologies, system concepts, military organizations, and operational concepts that might shift the nature of the competition to US advantage. Such a set of capabilities would provide the basis for a Third Offset Strategy. As was true of previous offset strategies, a Third Offset Strategy would seek, in a budget constrained environment, to maintain and extend US competitive technological and operational advantage by identifying asymmetric advantages that are enabled by unique US strengths and capabilities. A Third Offset Strategy would ensure that our conventional deterrence posture remains as strong in the future as it is today and would establish the conditions to extend that advantage into the future.

Today, the Third Offset Strategy is not a formal document that lays out a single course for future capabilities. Instead the term describes the broad nature of capabilities the Department expects to realize over the coming years by pursuing developments in advanced technologies by conducting experimentation with prototype systems to inform future options, through an increased emphasis on war gaming to help understand how new concepts can provide enduring advantage, and by emphasizing the need to innovate across the entire DOD enterprise, and through an emphasis on delivering new and enhanced capability to the warfighter in the coming years.

The Department anticipates that that the capabilities delivered through a Third Offset Strategy will:

- Enable the Joint Force to fight and deliver effects from a distributed posture at extended ranges
- Enable the Joint Force to leverage range, precision and speed to seize and maintain the initiative
- Enable the Joint Force to leverage dispersal and new forms of operational sanctuary to increase survivability
- Enable the Joint Force to achieve mass in the form of ensembles of many low-cost, collaborating "effectors"
- Enable the Joint Force to develop new forms of distributed maneuver and close combat techniques that combine kinetic, electronic warfare and cyber-enabled operations
- Enable the Joint force to operate battle networks much less vulnerable to cyber and electronic attack

Under a Third Offset Strategy, a combination of these capabilities, combined with the continued maturation of current US capabilities and strengths, will extend and enable US capability to project power and deliver dominant overmatch if called upon—rendering ineffective potential adversary investments in A2/AD capabilities and advanced weapons systems. These envisioned third offset capabilities will provide the underpinnings for future conventional deterrence and will provide the basis for support to US partners and Allies into the future.

Deputy Secretary of Defense Work has emphasized the importance of advanced software-enabled capabilities to any Third Offset Strategy.[3] Emerging capabilities in artificial intelligence and autonomy offer significant advantage to the Joint Force—enabling the future force to develop and operate advanced joint, collaborative human-machine battle networks that synchronize simultaneous operations in space, air, sea, undersea, ground, and cyber domains. Artificial intelligence will allow new levels of autonomy—the limited delegation of decision-making authority—within joint battle networks, leading to entirely new opportunities for human-machine collaboration and combat teaming.

With the goal of achieving future operational advantage, the Department is pursuing developments in five distinct areas enabled by recent developments in advanced algorithms and software intelligence:

- Autonomous Learning Systems—systems capable of processing large data sets to identify emergent patterns and models in near real time and/or that have the delegated authority to recommend or make decisions based on analysis of these data sets, especially in applications that require faster than human reaction times (e.g., cyber defense, electronic warfare, missile defense, and active vehicle protection systems

[3] Deputy Secretary Work's interview with David Ignatius at "Securing Tomorrow" forum at the Washington Post Conference Center in Washington, DC, March 30, 2016

- Human-Machine Collaboration—new capabilities that team human decision makers with software-enabled support systems to exploit the advantages of both for better and faster decisions
- Assisted Human Operations—using software enabled systems to enhance human perform in combat (e.g., wearable electronics and combat "apps")
- Manned-Unmanned Combat Teaming—advanced system-of-systems that employ innovative cooperative activities between manned and unmanned systems to provide new operational capabilities
- Cyber and Electronic Warfare (EW) Hardened and Networked-Enabled Semi-Autonomous Weapons—weapon systems that can locally communicate and coordinate their behavior for improved effectiveness in communications denied environments

Recent advances in advanced algorithms and software intelligence are expected to have significant impact in education, health care, and many commercial sectors in the coming decade. We anticipate US leadership in these areas to offer potential benefit in national security capabilities as well. We anticipate these emerging capabilities to ultimately support specific Service and Joint combat tasks and manifest themselves uniquely in domain-specific ways in support of new operational and organizational constructs.

As the Department develops a Third Offset Strategy, it is critical to prepare for a future security environment of continuous technological competition—one that will require sustained emphasis on the US maintaining its ability to out-innovate our competitors. This focus on innovation will require the Department to be open to all potential sources of technical advantage—leveraging our traditional industrial base, academia, and non-traditional suppliers to achieve competitive advantage. Speed of delivery from concept to fielding will be critical in this environment and will likely create a demand for new flexible architectures, more agile capability delivery models, and improved mechanisms for incremental capability and technology insertion. These factors will create a significant demand for a highly skilled defense science and technology workforce with an increased emphasis on ensuring the Department can attract and retain highly sought after talent.

FISCAL YEAR 2017 INVESTMENT IN THIRD OFFSET STRATEGY CAPABILITIES

In testimony [4] supporting the Fiscal Year 2017 Defense Budget Request, Secretary Carter identified more than $3.6 billion of investment in fiscal year 2017 and $18 billion in investment across the Future Year Defense Plan (FYDP) to help spur research, development, test and evaluation, and procurement of advanced capabilities our military will need to deter and if necessary fight and win high-end conflicts in the future. These investments directly support the objectives of a Third Offset Strategy.

While relatively modest compared to the Department's overall program, these investments will enable the development of leading-edge, asymmetric capabilities and help spur development of operational concepts to counter advanced adversaries. This approach is similar to the development and implementation of the Second Offset Strategy in the early 1980's—the initial Second Offset Strategy investments were a fraction of DOD's budget, but they ultimately led to the development of the joint guided munitions capabilities that have been used in every American conflict since Desert Storm.

The investments in the fiscal year 2017 Defense Budget Request include new capabilities that can be fielded rapidly through modifying and upgrading existing systems, material concepts that could immediately enter accelerated development, and technology-driven concepts that could have a significant impact on the Joint Force's conventional capabilities over the longer term. They also emphasize the critical importance of focusing on cost so that we will be able to introduce disruptive capabilities into the Joint Force at scale.

Many of the capabilities being developed to support a Third Offset Strategy remain classified, and therefore it is only possible to break down the $18 billion dollar investment publicly in six broad categories:

- First, to address the dual challenges of getting into theater (or the anti-access challenge) and operating under guided munitions threat (or the area-denial problem), the Department proposes investing more than $3 billion over the FYDP in weapons and concepts for surface-strike and air-to-air combat to negate competitor investments in these areas. These include upgrades to a num-

[4] Secretary of Defense's written statement before the Senate Armed Services Committee on March 17, 2016

ber of existing weapons and enhancements to on-going efforts to develop new weapons.

- Second, to insure our ability to prevail in future guided munitions salvo competition, the Department proposes investing nearly $500 million over the FYDP for improvements in cost-effective approaches to defend, disperse, and protect key operational capabilities and operational locations.
- Third, the Department proposes investing more than $3 billion over the FYDP to ensure we will continue to have the most lethal submarine and undersea force in the world. These investments will leverage new payloads, better sensors, and new undersea systems to enhance deterrence and ensure we continue to own this domain.
- Fourth, the Department proposes nearly $3 billion over the FYDP to advance the development of human-machine teaming, collaborative decision making, and efforts to disaggregate complex systems into many, lower-cost systems operating together to enable cooperative ensemble operations. When demonstrated, these capabilities will create radically new options for delivering combat power from disaggregated systems and will create significant operational and strategic dilemmas for potential adversaries.
- Fifth, we are investing more than $1.7 billion over the FYDP in cyber and EW capabilities including advances in cognitive systems that can sense, learn, and react automatically, and generate effective countermeasures against new or unknown threats in real time, ensuring our ability to operate within the cyber and EW domains while denying them to the adversary.
- Sixth, we are investing more than $500 million over the FYDP to expand war gaming, test new operational concepts, tactics, techniques and procedures, and fund demonstrations of advanced capabilities. A major focus will be exploring new operational concepts and capabilities for ground combat.

These summary investments include only the scope of programs that are supporting prototyping, experimentation, and operational demonstration and do not include the significant investments being made across the Department's Research and Engineering enterprise. Within the Service laboratories and DARPA, critical supporting technologies are being developed that will extend and enhance our ability to address future military challenges, shift the cost curve to improve affordability, or anticipate and create technological surprise. These core S&T investments maintain and extend the underlying foundational technical advantage on which current and future system innovations are based.

THE ROLE OF THE RESEARCH AND ENGINEERING ENTERPRISE

The Department's goal to sustain and advance our Nation's technological superiority for the 21st Century's national security environment requires sound research and development investments. The enhanced use of prototyping, demonstration, and experimentation will help the Department to more rapidly mature and assess the impact these technologies can have on our future force. Our investments focus on protecting essential US advantages in design, development, and manufacturing capabilities that would be very difficult to reconstitute if lost. These investments deliver the knowledge and tools necessary to preserve our advantage in a future global environment and provide the Department with the ability to make a strategic choice in the future to shape the nature of military competition.

The DOD Research and Engineering community works to create options for how the Department will meet our Nation's future national security needs and serve as an agile innovation engine for the Department. We must continue to focus on speeding the development and application of technology to meet acquisition program needs and must leverage ideas from inside and outside the Department; adapting and shaping them to solve military problems.

The ASD(R&E) serves as the Chief Technology Officer of the Department and provides oversight, guidance and direction to Service and Defense Agency science and technology investments. Through the Reliance 21 process, we coordinate the efforts of the Services to maximize return on investment and avoid unnecessary duplication of effort. Research and Development areas coordinated through the Reliance 21 process include efforts in Counter-Improvised Explosive Devices; Counter-Weapons of Mass Destruction; Biomedical; Command Control Communications; Computers and Intelligence; Human Systems; Cybersecurity; Autonomy; Engineered Resilient Systems; Electronic Warfare; Sensors; Air Platforms; Ground and Sea Platforms; Weapons Technologies; Space; Advanced Electronics; Energy and Power Technology; and Materials and Manufacturing Processes. Core work in each of these areas offers potential to impact and influence thinking relevant to a Third Offset Strategy, and

the Department continues to mature and update roadmaps for critical technology maturation across the Services in each of these areas.

The core science and technology efforts of ASD(R&E) and the service laboratories are principally focused on creating and enabling long-range opportunities for the Department's future materiel options. While these organizations also support the current fight and provide near-term support to ongoing operations, acquisitions, upgrades and support programs, their principal focus is on the mid- and long-range needs of the Department—creating the supporting technology and concepts to shape the Department's future.

In 2015, DOD conducted a classified ASD(R&E)-led long range research and development planning program (LRRDPP) to identify critical technologies and future system concepts that the Department should consider to inform material options for the future force. This study engaged experts from across the Department to identify novel system concepts and emerging technical capabilities that could have significant impact on DOD's posture relative to emerging near-peer competitors in the 2030 timeframe. This long-range study reviewed hundreds of inputs received from the commercial, not-for-profit, and academic sectors through a broad public request for information. The LRRDPP study also reviewed ongoing R&D efforts across Service laboratories, DARPA, and Department of Energy labs. The study delivered detailed recommendations for acceleration and shaping of new and existing DOD investments with the goal of providing technology options for demonstration in the 2020 timeframe. The Department's Fiscal Year 2017 Budget Request was informed by the LRRDPP study and other associated analytical efforts. The LRRDPP study was an effective means of injecting potentially technologically enabled disruptive concepts into the Department's budget deliberations—both to challenge current thinking and to provide long-range options for accelerated technology maturation for cutting-edge, asymmetric capabilities with the potential to enable new operational concepts.

DARPA similarly has an eye toward shaping the nation's future technology and technical options, but the DARPA portfolio is differentiated from the Service S&T portfolios by a distinctive focus on high-risk, high-payoff opportunities. Because DARPA's core mission is to make pivotal early investments in breakthrough technologies for national security, the Agency is always looking beyond the challenges of the moment to anticipate and create options for the future. The interaction between Service S&T community and DARPA is robust—with direct Service participation in DARPA programs and Service transition of DARPA-led efforts into the operational fleet. Through these interactions, the unique innovative culture of DARPA serves to catalyze and accelerate advanced capability adoption within the Services.

SCO was created in 2012 by Dr. Carter during his tenure as Deputy Secretary of Defense. SCO reports directly to the Deputy Secretary of Defense and is engaged in identifying and prototyping near-term solutions to counter the threat of near-peer competitors. SCO executes this mission by engaging directly with the COCOMS and Service leaders to identify opportunities to re-purpose, modify, or enhance existing Service capabilities to perform new missions. SCO efforts often cross service boundaries and mission areas—rethinking how tools procured by a Service for one mission might be repurposed and extended to provide alternatives and options in a fundamentally different mission area—often within a different Service. SCO's focus on demonstrating "good enough" and "sometimes game-changing in the near-term" solutions provide options to fill critical gaps and offer a rapid response to emerging threats—creating "breathing room" in which the Service S&T community and DARPA initiatives can deliver more fundamental, long-term solutions to provide sustained advantage.

As the Department pursues technology enablers for a Third Offset Strategy, each of these groups plays an important role. SCO is principally focused on the near-term—prototyping capabilities that, if successful, could be procured and implemented within the time horizon covered by the current President's budget submission. DARPA and the Department's core S&T enterprise are focused on concepts and enablers that, if successful, will have more fundamental shaping influence in the mid- to long-term. DARPA's portfolio consists of a selected set of fundamentally disruptive technology options, while the Services' S&T portfolios cover the full space of sustaining and emerging military relevant technologies.

CONCLUSION

As DOD develops a Third Offset Strategy, the Department's Research and Engineering enterprise is well prepared to develop, shape, and create technology options to inform future operational concepts. The core mission of the Research and Engineering community is to study emerging threat capabilities, develop, shape, and

evaluate emerging technological opportunities and to think creatively about alternative future capabilities. At each of our laboratories, engineering centers, and test facilities our best and brightest researchers come to work each day thinking about how to ensure that our military preserves its technological edge well into the future.

Our goal must always be to ensure that our soldiers, sailors, airman, and marines always have the scientific knowledge, the right technology, the advanced systems and tools, the decisive technology, and the material edge to succeed when called upon. Our Research and Engineering enterprise measures its success in the security of our Nation and the success of our warfighters.

The fiscal year 2017 President's Budget request will enable us to drive a culture of technical innovation across the Department, will help us prepare for an increasingly competitive global National Security environment, and will foster a whole-of-department coordinated effort across Army, Navy, Air Force, DARPA, and other DOD research and engineering organizations.

Let me close by thanking the committee for its strong interest in and support of the Department's research and engineering efforts as we work to discover, design, and deliver the technological capabilities our warfighters will need to shape the future.

Senator FISCHER. Thank you very much.

Dr. Prabhakar, please.

STATEMENT OF ARATI PRABHAKAR, DIRECTOR, DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

Dr. PRABHAKAR. Thank you. Chairwoman Fischer and Senator Nelson, members of the subcommittee, it's a great pleasure to be here with my colleagues today.

DARPA [The Defense Advanced Research Projects Agency] is part of the Defense Department, and we also work with defense companies and commercial companies, with universities and labs of all sorts, so we are very much part of a very large ecosystem. Within that ecosystem, DARPA has one particular mission, and that is to make the pivotal early investments in breakthrough technologies for national security. We do this work to change what's possible so that the Department can revolutionize our military capabilities.

Now, today's hearing is about the third offset strategy, and I want to just spend a little bit of time to tell you what it means for DARPA.

You know, DARPA's work is always—has always focused ono technologies to offset our adversaries' capabilities, so the third offset strategy hasn't significantly changed the way we start our programs, which range from radically new military systems to artificial intelligence to biological technologies. What is starting to shift, I think, in a very productive way is the kind of pull that we're getting from the Department to transition those technologies. I'll contrast what's going on today to the environment we were in 5 or 10 years ago. If you look in that period of time, most of DARPA's significant transition successes were direct to theater. We were tracking insurgents' pickup trucks from the air. We were helping to analyze data so that we could help commanders in the field understand the effectiveness of stability operations. We're very proud of the contributions that we were able to make in that environment. But, in that period of—and in a really intense focus, of course, on the ground war on counterinsurgency—in that period of time, we found that there was a very limited appetite in the Department to move ahead with the kinds of technologies that are going to be necessary to deter and defeat a very sophisticated nation-state adversary. That's what I think has really shifted today.

Today, when you look at what's happening across the Department, fresh thinking in many ways across the Department, including, of course, the third offset strategy. What that means today for DARPA is that many more of our transitions are working directly with the services in partnerships where we're exploring and experimenting and demonstrating what our technologies can do to counter, again, a very sophisticated adversary, a very capable opponent.

Just to give you one simple example, last week we had the great pleasure of christening a new ship. It's called the Sea Hunter. This ship will be the first—the world's first ship that's able to leave the pier to navigate thousands of miles across open seas without a single sailor onboard. What that means is that it'll be able to do some maritime missions for a tiny fraction of today's operating costs, which is good, but, even beyond that, this is the kind of new capability—this kind of unmanned ship now allows us to invent whole new ways to exercise influence across the vastness of the oceans. That's exactly what we're now doing with the Navy, a series of experiments that we're launching on—launching into with them. That's a partnership that I deeply value in this particular project with the Navy. It's a partnership I don't take for granted, however, because, when we started that program, originally called the Active Program, many years ago now at DARPA, starting in the early part of this decade, at that time we were going it alone, for a couple of reasons. Obviously, because, at that time, the technology was very new and unproven, but also partly because the Navy's priority at that time, as was the whole Department's—their focus was on the battle at hand.

Today, very much in contrast to that, the Sea Hunter Project is actually only one of a growing set of partnerships that we have, transition relationships that we're building with the services. Those cover every kind of operational domain. I mentioned maritime, but also work in the air, space, and ground domains, also work to control the electromagnetic spectrum in cyber, and in the information domain. At DARPA, we see these partnerships as absolutely essential if we're going to get these DARPA technologies from wild new idea to robust operational capability.

Let me just conclude this afternoon by touching on two pillars of your support that make it possible for DARPA to do this work:

One is, of course, the budget. Your support in—of the budget over the last few years has been vital in the relative stability that we've enjoyed. I'll ask you again for your full support of the President's budget request.

The second is people. I want to give a special thanks to this committee for, first, creating and then many—over many years, supporting a special hiring authority, the 1101 hiring authority. This is one of the big reasons that DARPA is able to move fast and to hire exceptional people.

Those are the two elements: great people and the trust that you place in us. This is why DARPA is able to create breakthrough technologies for national security.

Thank you. I'll look forward to your questions.

[The prepared statement of Dr. Prabhakar follows:]

PREPARED STATEMENT BY ARATI PRABHAKAR

Chairman Fischer, Ranking Member Nelson and Members of the Subcommittee, thank you for the opportunity to testify before you today. I am Arati Prabhakar, Director of the Defense Advanced Research Projects Agency, better known as DARPA. It is a pleasure to be here with my colleagues from the Department of Defense (DOD) research and development community to discuss DARPA's investments in breakthrough technologies for national security and in particular our contributions to the Department's Third Offset Strategy.

For nearly six decades, DARPA has played a particular role in this community of government innovators, and in the larger U.S. technology ecosystem: to pursue extremely challenging but potentially paradigm-shifting technologies in support of national security. Today I will focus my remarks on DARPA's role in the development of technologies to offset the advanced threats that our military and our Nation will face in the years ahead, and on the next generation of advanced military capabilities to deter and if necessary defeat highly sophisticated adversaries.

A CHANGING WORLD

Our senior military and civilian leaders face a world of kaleidoscopic uncertainty today and into any foreseeable future. The daily fare includes a noxious stew of violent extremism, terrorism, and cross-border criminal activity. At the same time, the actions and intentions of nation states in every region are increasingly demanding DOD's focus and attention. Arsenals in some of these nations have grown substantially in the past decade, and recent provocative actions by nations around the world have made clear that their capabilities have grown as well. Moreover, several U.S. peer adversaries today boast first-rate scientists, engineers, laboratories and industries, raising the stakes for future capabilities considerably. Our challenge at DARPA and for DOD is to maintain a significant advantage for military and national security purposes against this competitive and shifting backdrop.

To achieve this advantage, the Department has embarked on an important shift in recent years to reenergize its ability to invent, experiment with and operationalize advanced military capabilities that will be critical to deter and if necessary defeat the emerging great powers of this century. DOD's Third Offset Strategy and its Long Range Research and Development Plan (LRRDP) embody this important shift.

Technological capabilities are only one dimension in these strategies. This is where DARPA makes it contribution. Because DARPA's core mission is to make pivotal early investments in breakthrough technologies for national security, the Agency is always looking beyond the challenges of the moment to anticipate and create options for the future. As a consequence, DARPA plays two roles in the Department's Third Offset Strategy and the LLRDP. The first role is the obvious one: developing and demonstrating critical core technologies for these new strategies through the execution of a wide portfolio of DARPA programs. A second role that DARPA plays is sharing its expertise and perspectives on future technologies to inform how these Departmental strategies are shaped.

These two roles are reflected in twin principles that guide our thinking at DARPA. One principle is that in the years ahead, the most powerful defense systems will come from the tight integration of leading-edge commercial technologies and highly specialized military technologies. You will see this approach in many of our programs, from tablets with added encryption for close air support to state-of-the-art digital electronics with added DOD-unique radio chips for leapfrog radio frequency (RF) systems. The second key principle is that future U.S. military success will lie in building systems that are designed to evolve, grow and adapt.

This second principle is critical in light of a significant difference between the Third Offset and previous offsets. While previous offsets had as their goal bursts of accelerated technological progress to provide comfortable, multi-decadal leads over our adversaries, it is unlikely the United States will again enjoy such monopolies on advanced technologies. Unlike the decades following the Second World War, global connectedness and the democratization of sophisticated scientific and engineering skills and capabilities make the maintenance of such steep technological gradients all but impossible today. That means that rather than striving for a temporary, static advantage for a period of years, the Third Offset must deliver immediate advantages with built-in evolutionary capacities and a portfolio of more fundamental, enabling technologies that can support a long-term succession of iterative advances and assurance of ongoing momentum and pace. In short, we must design not just a new point of capability, but new curves of expanding capability over time.

In similar fashion, my testimony today will focus on two collections of DARPA research programs relevant to the Department's Third Offset Strategy. The first col-

lection includes examples of efforts that are focused on the development of next-generation technologies to counter next-generation adversaries. The second collection includes examples of efforts that are more fundamental in nature and are laying the foundation for advances even further in the future. Within each of these two categories, I have organized our efforts into three groups, representing three degrees of technological maturity: technologies already being piloted or used ("Adoption and Impact"), those currently in development ("Technical Progress") and those that are inspiring new investments but that have hallmarks of longer-term, outsized potential ("New Opportunities").

DARPA'S INVESTMENT PORTFOLIO

Next-generation Technologies to Counter Next-generation Adversaries

DARPA aggressively pursues technologies with the potential to expand DOD's range of tactical and strategic options and impose technological surprise on our adversaries. Our work spans every traditional domain of conflict, including maritime, ground, air and space, as well as the cyber and biological domains. It embraces not only traditional military hardware but also core mission systems such as communications, radar, electronic warfare, and position, navigation and timing systems. At DARPA, a crosscutting theme across all of these areas is the need to escape from reliance on today's highly capable but monolithic and expensive platforms in favor of a more diversified array of platform architectures that are smaller and heterogeneous and thus harder to target, less expensive and more easily upgraded, and can ultimately produce more powerful effects than any single platform by itself. DARPA's challenge is to imagine, design and develop the separate but networked components of this new paradigm and demonstrate the power of complex but seamless systems of systems.

ADOPTION AND IMPACT

Communications Under Extreme RF Spectrum Conditions (CommEx)

DARPA's CommEx program is developing technologies that can characterize the jamming environment and then actively suppress enemy jamming, so aircraft can still communicate with each other in a highly contested RF environment. Initial components of CommEx technology are part of a planned upgrade to the widely used Link 16 air-to-air data network.

Cognitive Electronic Warfare (EW)

DARPA's Advanced RF Countermeasures (ARC) and Behavioral Learning for Adaptive Electronic Warfare (BLADE) programs are investing in the technologies needed to rapidly react to dynamic electromagnetic spectrum signals from adversary radar and communications systems. These programs are applying machine learning—computer algorithms that can learn from and make predictions from data—to react in real time and jam signals, including new signals that have not yet been cataloged. DARPA is working with the Services to transition technologies derived from the field of cognitive electronic warfare into the F–18, F–35, Army Multi-Function EW program, and Next Generation Jammer.

Power Efficiency Revolution for Embedded Computing Technologies (PERFECT)

DARPA's PERFECT program is developing revolutionary approaches to improving the energy efficiency of DOD computational systems, an improvement that will embed significantly increased computing capabilities including modern learning algorithms on power-limited platforms such as UAVs. Resulting technologies are transitioning to both commercial and government users, with the National Reconnaissance Office adopting them for new, radiation-hardened circuit architectures that enable extremely high data-throughput next-generation space systems. A consortium of companies including Google, HP and Oracle, is pursuing power-efficient open-source hardware, such as RISC–V open-source cores developed in part with PERFECT funding.

Long Range Anti-Ship Missile (LRASM)

DARPA and the Office of Naval Research (ONR) collaborated to develop the Long Range Anti-Ship Missile (LRASM), an advanced anti-ship missile capable of operating at extended ranges with reduced dependency on intelligence, surveillance and reconnaissance (ISR). The collaboration began as a technology demonstration effort in early 2009. The first two flight tests were conducted in the fall of 2013, during which all demonstration objectives were met. To ensure speedy and seamless development and deployment of this new capability, DARPA created and at first led a LRASM Deployment Office (LDO) with the Navy and Air Force, as LRASM

transitioned to a Navy Program of Record. A third flight test, conducted in February 2015, further assessed technical maturity. This past December the Navy took over the LDO directorship, marking the successful transition of a model collaborative effort to address a pressing strategic need.

Research on Fresh Approaches for Computer Security

DARPA's Clean-slate design of Resilient, Adaptive, Secure Hosts (CRASH) program was a basic research effort that designed new computer systems that are highly resistant to cyber attack. The technology development has recently concluded, and CRASH-developed software is now being incorporated in the commercial and military arenas. One university performer started a company based on CRASH research; this led to an announcement from HP in September 2015 that its new line of printers would feature this software to enhance their security. DARPA is coordinating transitions to the Navy and the Defense Information Systems Agency (DISA). For example, the aforementioned software is now being transitioned to the Naval Surface Warfare Center to protect shipboard control systems from cyber attack, and other CRASH software is being transitioned to offer similar protection for DOD command and control servers. Additionally, the Department of Homeland Security and the Air Force Research Laboratory have been working together to test and evaluate CRASH technology in multiple devices. Because the cyber-attack surface is vast and diverse, each of these transitions makes a contribution to the Nation's cybersecurity by taking a class of threats off the table.

Active Authentication

Passwords are cumbersome and imperfect authentication systems for use on information systems, and most systems have no way of verifying that the user who was originally authenticated is the user still in control of the keyboard. DARPA's Active Authentication program is addressing this problem by developing novel ways of validating identity—ways that focus on unique aspects of the individual through the use of software-based biometrics, including behavioral traits such as subtleties in keystroke style or screen-swipe patterns. Although these biometrics may never completely replace passwords, they can provide an added layer of assurance of a user's identity—and DARPA-developed systems have begun to make their way into commercial products, where they are already in use by millions of users. One version, for example, has been incorporated into Google's new Android behavioral authentication system announced last June; others are being piloted by several banks in the United States and Europe, where they have helped secure more than 1.5 million transactions; and yet others are being explored by the National Institute of Standards and Technology for possible use within the National Strategy for Trusted Identities in Cyberspace (NSTIC).

TECHNICAL PROGRESS

Unmanned Surface Vessel for Long-Duration Missions

The Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessel (ACTUV) program has designed, developed and constructed an entirely new class of ocean-going vessel—one able to traverse the open seas for months and over thousands of kilometers without a single crew member aboard. The 130-foot ship is designed to robustly track quiet diesel electric submarines. But of broader technical significance, it embodies breakthroughs in autonomous navigational capabilities with the potential to change the nature of U.S. maritime operations. Specifically, ACTUV is endowed with advanced software and hardware that enables full compliance with maritime laws and conventions for safe navigation—including international regulations for preventing collisions at sea, or COLREGS—while operating at a fraction of the cost of manned vessels that are today deployed for similar missions. ACTUV was recently transferred to water at its construction site in Portland, Ore. It is scheduled to be christened on April 7, with open-water testing to begin this summer off the California coast.

XS–1

The objective of the Experimental Spaceplane XS–1 program is to demonstrate the technology needed to fabricate and fly a reusable aircraft to the edge of space—and be able to do so 10 times in 10 days, to demonstrate "aircraft-like" operability, cost efficiency and reliability. Success would radically alter the current space-access equation in which launches must be arranged years in advance. That bottleneck not only adds to the cost of placing national security payloads on orbit but also forces an increase in the complexity of the payloads themselves. In an era of declining budgets and proliferating foreign threats to U.S. air and space assets, routine, affordable and responsive access to space is essential to enabling new military space

capabilities and rapid reconstitution of space systems during crisis. Specific goals of XS–1 include an ability to deploy a small expendable upper stage to launch a 3,000-pound spacecraft to low-Earth orbit at a cost of $5M, ten times less than today's launch systems.

System of Systems for Air Superiority

In recent years, DARPA has started a collection of programs that aims to develop and demonstrate technologies that together can dramatically advance air combat capabilities against sophisticated adversaries by coordinated deployment of distributed assets with diverse capabilities rather than reliance on densely consolidated capabilities on large, expensive and unwieldy platforms. Key to these efforts is the approach of integrating new capabilities with existing systems to achieve cost leverage against near-peer adversaries and to continuously progress faster and at lower cost than traditional monolithic platform-based approaches.

DARPA's System of Systems (SoS) Integration Technology and Experimentation (SoSITE) program is developing novel architectures—combinations of different types of aircraft, weapons, sensors and mission systems—that distribute air warfare capabilities across a large number of interoperable manned and unmanned platforms. In the last year, we developed an analytical capability to compare the mission performance and cost leverage of alternative architectures and found several promising approaches to achieving air dominance in highly contested environments. The technical and operational risks associated with these approaches are being analyzed this year to provide the basis for our flight experimentation program in the next phase of the program.

The Distributed Battle Management (DBM) program is one key component of the Agency's system-of-systems vision. Current battle management systems offer only limited automated aids to help warfighters comprehend and adapt to dynamic situations. Adding more elements to the SoS architecture—more unmanned aircraft, missiles and mission systems—will exacerbate the battle management challenge, as will the degraded communications of a highly contested environment. The DBM program seeks to develop appropriately automated decision aids to assist airborne battle managers and pilots manage air-to-air and air-to-ground combat. In the initial phase of the program, we developed algorithms to disseminate hostile track data using limited communications across tactical data links. These algorithms achieved high accuracy while requiring less communications capacity then standard approaches. We also developed algorithms for automatic control of UAVs in conducting air-to-air and air-to-surface engagements. In the next phase of the program, these algorithms will be integrated with appropriate human-computer interfaces. The resulting capability will be evaluated by pilots and operators in a virtual simulation environment.

High-Assurance Cyber Military Systems (HACMS)

Embedded processors are the ubiquitous computational brains in DOD systems, but along with their valuable capabilities comes an ever-growing attack surface for cyber malfeasance. DARPA's HACMS program is developing tools and methods for the design and construction of high-assurance cyber-physical systems—scaling the mathematics of formal methods to create devices effectively "unhackable" for specified properties. DARPA has applied these techniques initially to a Little Bird helicopter, using a HACMS microkernel to give the mission computer a cyber retrofit. In a flight test, a red team was unable to attack the helicopter's controls, despite the fact that the team was given access to the platform and its software, including its source code.

Cyber Grand Challenge (CGC)

It typically takes months or years for a software bug to be identified and patched—a period of time increasingly being taken advantage of by digital miscreants, and a vulnerability window not likely to shrink as long as the process for identifying and repairing such flaws remains mostly manual and artisanal as it is today. CGC is a DARPA-sponsored competition that aims to accelerate the development of automatic defensive systems capable of reasoning about flaws, formulating patches and deploying them on a network in real time. By acting at machine speed and scale, these technologies may someday overturn today's attacker-dominated status quo. Seven teams from across the United States qualified last year to compete in the CGC final event, which will take place August 4, 2016, live on stage, co-located with the DEF CON 24 conference in Las Vegas.

Mining and Understanding Software Enclaves (MUSE)

DARPA's MUSE program seeks a radical rethinking of the way we conceive and maintain software, by integrating foundational ideas from formal methods and ma-

chine learning to an ever-growing corpus of open-source software. The techniques being developed under MUSE are intended to discover deep semantic properties from the programs found in its corpus. These properties drive two distinct analytic tasks. The first enables automatic identification and repair of software bugs by recognizing anomalous structure based on properties found in similar previously analyzed programs; the second synthesizes new software behavior from existing corpus elements based on formal specifications. To date, DARPA has assembled a software corpus of more than 20 terabytes and has successfully applied its technologies to automatically synthesize a provably correct implementation of sophisticated cryptographic protocols such as Advanced Encryption Standard (AES), and repair well-known security vulnerabilities such as Heartbleed.

NEW OPPORTUNITIES

Maritime System of Systems

DARPA has made important technical progress towards future air dominance through the development of a systems-of-systems approach. Now, through its Cross Domain Maritime Surveillance and Targeting (CDMaST) program, DARPA is extending this model into the maritime domain. The program will be developing technologies to disaggregate various functions across multiple lower cost, upgradable and in many cases unmanned platforms on the sea surface and underwater. By distributing the functions of position, navigation and timing; communications; command and control; and networking and logistics across large expanses, this architecture will force the adversary to defend a very wide area at high cost, inverting the cost curve for securing the maritime environment.

Leading-edge Electronics with Built-in Trust

Under the hood of every military system are the electronic components that are its brains, eyes and ears, but DOD has struggled for decades with contradictory demands in designing, sourcing and maintaining these vital components. Military systems need the most capable integrated circuit (IC) technology to do their phenomenally difficult computational or signal-processing tasks with the limited power available on a missile or aircraft. Yet designing custom ICs continues to grow more complex, and fewer teams are able to commit the time and money for custom design, even in the commercial world. At the same time, security is essential for military applications but semiconductor production has globalized, with diminishing U.S.-owned, U.S.-sited production capacity at the leading edge of technology, and supply chains now crossing multiple national borders. While IC technology progresses at a pace set by the commercial sector, DOD needs access to components for decades. To address this group of challenges, DARPA is building a cluster of programs aimed at creating new options for DOD.

DARPA's Trusted Integrated Circuits (TRUST) program is developing technologies that will ensure the trustworthiness of ICs used in military systems, even when those components have been designed and fabricated under untrusted conditions. TRUST makes a radical departure from conventional verification approaches, using advanced metrics to identify with increasing efficiency ICs that have been maliciously attacked while reducing the incidence of declaring good circuits to be bad.

The Supply Chain Hardware Integrity of Electronics Defense (SHIELD) program aims to eliminate counterfeit ICs from the electronics supply chain by inserting into the packaging of these components minuscule "dielets"—chips tinier than a grain of salt, with embedded encryption, sensors, near-field power and communications capabilities—to detect any attempt to tamper with the relevant electronics. Dielets are being designed to incorporate passive, unpowered sensors capable of capturing attempts to image, de-solder, de-lid or image the IC; mechanical processes that make the dielet fragile and prevent intact removal from its package; and a full encryption engine and advanced near-field technology to power the dielet and provide communications, to make counterfeiting too complex and time-consuming to be cost effective.

DARPA's Integrity and Reliability of Integrated Circuits (IRIS) program is developing techniques to provide system developers the ability to derive the function of digital, analog and mixed-signal ICs non-destructively, given limited operational specifications. These techniques include advanced imaging and device recognition of deep-sub-micron circuits, as well as computational methods to determine device connectivity. The program is also working to better understand circuit aging systems and to produce innovative methods of device modeling and analytic processes to determine the reliability of integrated circuits by testing a limited number of samples. Resulting technologies will help ensure that DOD microelectronics reliably

perform as expected and only as expected by revealing potential compromises due to manufacturing defects, counterfeiting or the addition of malicious components.

The Circuit Realization at Faster Timescales (CRAFT) program seeks to develop new fast-track circuit-design methods, multiple sources for IC fabrication and a technology repository that will facilitate reuse of proven solutions. To achieve its goals, CRAFT seeks to shorten the design cycle for custom integrated circuits by a factor of 10 (on the order of months rather than years); devise design frameworks that can be readily recast when next-generation fabrication plants come on line; and create a repository so that methods, documentation and intellectual property need not be reinvented with each design and fabrication cycle.

Cybersecurity for the Grid

Embraced by two vast oceans and sharing borders with only two nations—both of them allies—the United States has long enjoyed a degree of insular security. But our critical infrastructure's growing dependence upon cyber systems inherently accessible even from long distances means that the prospect of attacks against the homeland must now be taken very seriously. Indeed, with cost pressures having driven the integration of conventional information technologies into the nation's dispersed industrial control systems, today'sgrid is increasingly vulnerable to cyber attack, either through direct connection to the Internet or via interfaces to utility information technology systems. DARPA's recently launched Rapid Attack Detection, Isolation and Characterization Systems (RADICS) was created to develop automated systems that would help cyber and utilities engineers restore power within seven days of an attack that overwhelms the recovery capabilities of power providers. RADICS's goals include the development of advanced anomaly-detection systems with high sensitivity and low false-positive rates, based on analyses of the power grid's dynamics; the development of systems that can localize and characterize malicious software that has gained access to critical utility systems; and the design of a secure emergency network that could connect power suppliers in the critical period after an attack.

Foundational Technologies to Support Long-term, Successive Advances

In addition to pursuing the kinds of game-changing technologies described above, DARPA has the responsibility for investigating research areas that are so new and unformed as to exist more as inklings than disciplines. This is the part of our portfolio that anticipates and prepares for varieties of threats that are still poorly understood but have the potential to wreak entirely new kinds of havoc—including the fast-evolving field of biology, which has outsized potential for strategic surprise but has not traditionally been at the core of the Nation's national security framework. It is in this part of DARPA's portfolio that the seeds of future offsets are being discovered and cultivated. While the outcomes of these efforts are inherently less predictable than those of other programs, these efforts also have the most dramatic long-term potential to generate truly revolutionary capabilities that can counter categories of risk hardly imaginable today.

ADOPTION AND IMPACT

Additive Manufacturing for Performance Applications

Despite its revolutionary promise, additive manufacturing is still in its infancy when it comes to understanding the impact of subtle differences in manufacturing methods on the properties and capabilities of resulting materials. Those uncertainties have slowed the reliable mass production of additively manufactured structures with demanding specification requirements, such as structural components for aircraft and other military systems. To overcome this problem, DARPA's Open Manufacturing (OM) program is building and demonstrating rapid qualification technologies that comprehensively capture, analyze and control variability in the manufacturing process to predict the properties of resulting products. Success could help unleash the potential time- and cost-saving benefits of advanced manufacturing methods for a broad range of defense and national security needs.

DARPA's OM framework and data schema are already being used by the Navy in their efforts to produce flight-critical metallic components with an additive-manufacturing-certified Technical Data Package, with plans to field a set of flight-critical metallic components for the V–22, H–1, and CH–53K platforms by 2017. Manufacturing pedigree considerations, such as a baseline set of standards and schema for additive manufacturing data collection, are being provided by the OM Manufacturing Demonstration facilities at Penn State and the Army Research Laboratory. In another application, advanced manufacturing approaches for bonded composites could enable aircraft wings and fuselages, for example, to be built and joined together without the thousands of rivets and fasteners currently required, signifi-

cantly reducing manufacturing costs and time and lowering operating costs by making aircraft lighter.

Accurate, Specific Disease Diagnostics on the Spot

The challenge of tracking the spread of infectious disease is exacerbated by the fact that the only way to know precisely which pathogen ails a patient is to draw blood, send it to a lab, and often wait days to hear the result. The Mobile Analysis Platform (MAP) point-of-care diagnostic device is a simple, rugged, handheld, battery-operated instrument that rapidly identifies a range of infectious diseases. Developed under DARPA's Prophecy program, it enables low-cost and robust molecular diagnostics within 30–45 minutes in areas where neither a laboratory nor a secure cold chain is available. Because the device provides instant wireless transmission of test results and location data, it can provide invaluable real-time epidemiological data during outbreaks of fast-moving diseases such as Ebola. DARPA is already engaged in clinical testing of the device with the Naval Health Research Center and the U.S. Military HIV Research Program, and will conduct testing with the Marine Corps Warfighting Laboratory this year during military exercises in the United States and West Africa. In addition, DARPA recently initiated development of a MAP assay for Zika virus.

Biologists, Start Your Startups!

For many of the technologies driven by DARPA's Biological Technologies Office, the path to impact runs through commercialization. Several recent examples point to early progress in this regard.

DARPA's Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT) program is creating a new technology base to outpace the spread of natural or engineered diseases and toxins through the development of rapid diagnostics, novel vaccines, new methods for drug delivery and entirely new approaches to providing populations with antibody-derived immunity. Among other technology and business successes resulting from ADEPT are a DARPA-enabled spin-off that has since received more than $25 million in venture funding for further development of a novel diagnostic platform and another small biotech company for which DARPA provided the initial research funding that went on to receive venture funding to continue development of tissue-integrated biocompatible sensors.

DARPA's Microphysiological Systems (MPS) program—better known as the Agency's foray into "organs-on-a-chip" technology—is developing a platform that uses engineered human tissue to mimic human physiological systems as a means of testing the safety and effectiveness of candidate drugs, vaccines or other biomedical countermeasures. In one of many applications, two DARPA performers are collaborating to understand the liver toxicity that can be caused by biological therapeutics—a common reason why otherwise promising drug candidates fail in clinical trials. Among the program's business successes are a start-up microfluidics company spun off from the research that DARPA had funded, which has since gone on to raise more than $10 million in venture funding.

TECHNICAL PROGRESS

Harnessing Extreme Physics

Through a number of ambitious basic science programs, DARPA is pushing the limits of the physical sciences, opening new possibilities for ultra-precise measurements and unprecedented control over fundamental phenomena. Among them:

The science of quantum communications—in which single photons from entangled photon pairs are transmitted over a distance—offers the possibility of unconditionally secure communication because the act of measuring a quantum object necessarily changes it. For quantum communications to be practical, however, several technological barriers must be overcome. DARPA created the Quiness program to investigate novel technologies capable of high-rate, long-distance quantum communications. Recent demonstrations through Quiness of technologies to capture, manipulate and re-transmit photons without in effect measuring them are truly significant. This is because theorists in Quiness were able to prove from fundamental quantum principles that such "quantum repeater" technologies are the only way to achieve quantum communications over trans-continental distances.

Many defense-critical applications—the Global Positioning System (GPS) and the Internet, for example—demand exceptionally precise time and frequency standards. Today's systems, however, rely on 1950s atomic physics technologies. Recent advances in optical atomic systems give promise to a new generation of optical atomic clocks and quantum metrology that stands to transform numerous DOD applications. The Quantum-Assisted Sensing and Readout (QuASAR) program is developing new quantum control and readout techniques to provide a suite of measure-

ment tools that will be broadly applicable across disciplines, with likely applications relating to biological imaging, inertial navigation and robust global positioning systems. Recently the program demonstrated the world's most accurate clock with a total uncertainty of 2 parts in 1018, or about 10,000 times better than GPS clocks. This means that if the clock began ticking at the Big Bang nearly 14 billion years ago it would be accurate to better than one second today. Clocks of this caliber could lead to improved positioning and navigation, and enable novel imaging and geological sensing techniques.

DARPA's Ultrafast Laser Science and Engineering (PULSE) program is developing the technological means for engineering improved spectral sources, such as ultra-fast optical lasers—advances that in turn could facilitate more efficient and agile use of the entire electromagnetic spectrum and generate improvements in existing capabilities such as geolocation, navigation, communication, coherent imaging and radar, and perhaps give rise to entirely new spectrum-dependent capabilities. Recent PULSE demonstrations include synchronization of clocks with femtosecond precision across kilometers of turbulent atmosphere, corresponding to a 1,000-fold improvement over what is possible using conventional radio-frequency techniques.

NEW OPPORTUNITIES

Changing the Security-Privacy Trade-off

DARPA's Brandeis program will explore technologies that could help break the tension between maintaining privacy and being able to tap into the huge value of data. Rather than having to trade off between these important goals, Brandeis aims to build a third option, enabling safe and predictable sharing of data while reliably preserving privacy. Assured data privacy could help open the doors to a number of security-relevant goals, from collections of publicly available data that can help predict military movements or emergency situations to early evidence of cyber attacks on shared networks—applications that in some environments could be difficult to fully implement without assurances of privacy.

Communicating with Computers

A new and powerful wave of artificial intelligence (AI) is sweeping commercial and military applications today. Based on recent major advances in machine learning—research that was sponsored in part by DARPA—this generation of AI is fueling fields as disparate as search, self-driving cars and financial trading in the commercial world and battle management, electronic warfare, cybersecurity and information operations in the national security realm. I have touched on some of these examples in my testimony today.

Despite this significant technical progress, however, the ways in which we humans interact with machine systems are still quite limited compared to human-to-human interactions. DARPA's Communicating with Computers (CwC) program is a basic research effort to explore how to facilitate faster, more seamless and intuitive communication between people and computers—including how computers endowed with visual or other sensory systems might learn to take better advantage of the myriad ways in which humans use contextual knowledge (gestures and facial expressions or other syntactical clues, for example) to enrich communication. Ultimately, advances from this program could allow warfighters, analysts, logistics personnel and others in the national security community to take fuller advantage of the enormous opportunities for human-machine collaboration that are emerging today.

All the Light We Cannot See

Light that enters the eye or the lens of a camera carries much more information than is typically retrieved by viewers, including numerous details about where it has been and what it has experienced. DARPA's Revolutionary Enhancement of Visibility by Exploiting Active Light-fields (REVEAL) program seeks to unlock information in photons that current imaging systems discard. The program is first developing a comprehensive theoretical framework to enable maximum information extraction from complex scenes by using all the photon pathways of captured light and leveraging light's multiple degrees of freedom. This framework will then be used to guide the development of new imaging hardware and software technologies. Those technologies will be tested against a challenge problem that calls for full 3D scene reconstruction from a single viewpoint—a rendering that today requires inputs from multiple viewpoints. Such an ability could enhance situational awareness for troops, potentially allowing them to reconstruct, from a single vantage point, a complex scene including objects or people not visible by line-of-sight viewing.

Designing Complex, Dynamic Systems

DARPA's Complex Adaptive System Composition and Design Environment (CASCADE) program has a seemingly esoteric but ultimately practical goal: to advance and exploit novel mathematical techniques to gain a deeper understanding of system component interactions, a unified view of system behaviors and a formal language for composing and designing complex adaptive systems. Conventional modeling and design tools invoke static 'playbook' concepts that do not adequately represent the complexity of, say, an airborne system of systems with its constantly changing variables, such as enemy jamming, bad weather or loss of one or more aircraft. CASCADE aims to fundamentally change how systems are designed to enable real-time resilient response within dynamic, unexpected environments.

KEEPING DARPA VIGOROUS

The programs described above are a sampling of what engages DARPA every day, but of course DARPA is much more than a collection of programs. It is a team of about 200 extraordinary government employees whose collective energy not only propels the Agency but also invigorates scientists, engineers, mathematicians and others across the wide community with which we work—defense companies large and small, commercial startups and major firms, universities, government agencies and labs, and our close partners across DOD. It is a team that revels in the opportunity to attack pressing, nearly intractable problems—all in the context of public service.

DARPA's leadership takes seriously its responsibility to encourage the Agency's culture of high-risk, high-reward innovation and its ability to execute rapidly and effectively. Toward that end, we continue to experiment with better ways to reach new performers through, for example, the "EZ BAA" process launched by our Biological Technologies Office last year, which greatly simplifies the process by which performers can get on contract with DARPA for efforts of up to $750,000. The EZ BAA is especially helpful in reaching those unfamiliar with defense procurement.

We also continue to use our prize authorities, for which we are grateful. Prize authorities were crucial to the success of the DARPA Robotics Challenge, our three-year push to accelerate progress in ground robotics for humanitarian assistance and disaster relief, which held its finals in California last summer. We are also using our prize authorities to run DARPA's Cyber Grand Challenge, which has been working to speed the development of automated cyber defense capabilities and will hold its final competition in August, when seven extremely talented teams will have their computers face off against one another at an event that is expected to draw thousands of spectators. In addition, we continue to use the prize mechanism for smaller efforts, such as last year's competition to model the spread of Chikungunya, a mosquito-borne infectious disease.

Of course, at the center of DARPA's success is an abiding commitment to identify, recruit and support excellent program managers—extraordinary individuals who are at the top of their fields and who are hungry for the opportunity to push the limits of their disciplines during their limited terms at DARPA. I am most grateful for the critical support this Subcommittee provided in authorizing the 1101 hiring mechanism, extending it, and in fiscal year 2015 expanding DARPA's ability to use it. That authority has proven invaluable to our ability to attract some of the finest scientists, engineers and mathematicians to the important work of public service and national security. The 1101 experiment has now been running since 1999 and has clearly proven its benefits to DARPA and the Nation. After 16 years of annual uncertainty about its ongoing availability, we would appreciate your support to make this authority permanent.

DARPA'S BUDGET

The President's fiscal year 2017 budget request for DARPA is $2.973 billion. This amount is the same as that requested for fiscal year 2016 and $105 million more than the $2.868 billion appropriated for fiscal year 2016. To put these numbers in context, from fiscal year 2009 to fiscal year 2013 DARPA's budget eroded significantly through a series of reductions, including the 8 percent across-the-board sequestration cut in fiscal year 2013. The total reduction to DARPA's budget from fiscal year 2009 to fiscal year 2013 was 20 percent in real terms. With modest increases in fiscal year 2014 and 2015 and a slight decrease for fiscal year 2016, DARPA's budget has not fully recovered, but it has been more stable. I ask for your full support of the President's budget request for fiscal year 2017 so that DARPA can continue to deliver on its vital mission.

CONCLUSION

As the programs I have highlighted today illustrate, DARPA's commitment to bolstering national security encompasses an extraordinary range of technologies and scientific domains, spanning dimensional scales from the atomic to the celestial, time scales from attoseconds to decades, spectral scales from radio waves to infrared to gamma rays, andbiological scales from genes and proteins to neurons and organs to infectious diseases and global health. Every day, the people of DARPA come to work to probe and push on those various frontiers. Despite the daunting security challenges around the globe that spur our work, the atmosphere within our agency is persistently one of excitement and even joy—a reflection of the fact that DARPA is obsessed not with problems but with solutions.

A highly functional, effective and spirited organization does not happen by accident. We within DARPA work at it constantly, drawing our inspiration from the amazing, ever-evolving world of technology and from a deep desire to serve our Nation. I and my colleagues at DARPA appreciate the ongoing support and trust this committee and subcommittee have bestowed upon DARPA. I am fully committed to ensuring that, just as past investments in DARPA helped secure our Nation by repeatedly bending the arc of technological history, so today's investments will give rise to capabilities that will protect our Nation and project our interests for many decades to come.

With that, I will be pleased to respond to your questions.

Senator FISCHER. Thank you.

Dr. Roper.

STATEMENT OF WILLIAM B. ROPER, JR., DIRECTOR, STRATEGIC CAPABILITIES OFFICE

Dr. ROPER. Chairman Fischer, Ranking Member Nelson, and members of the committee, thank you for your interest in the third offset. Thank you for your interest in the Department's return to great-power competition. Thank you for your interest in the Strategic Capabilities Office, or SCO. It's an honor to be here with colleagues from the research-and-development arm of the Department who are striving to maintain our technology edge against a world of threats.

As mentioned earlier, these threats now span a space from nonstate terrorism all the way up through great-power competition. The third offset is really trying to return a greater focus of our Department's effort, including the budget, to those highly sophisticated adversaries. In 2012, the SCO was created by Secretary Carter as one piece of this broader strategy; specifically, a near-term piece that is focused on trying to regain advantage. I would like to discuss the way that we frame immediate challenges, our process for prototyping solutions, and how we're working to do these prototypes in a partnership with the services. This will be the focus of my remarks today.

Though daunting in many respects, we interpret our immediate challenges via a fairly simple analogy, but an instructive one, that the U.S. military is akin to a football team that has run a very successful playbook, but for a bit too long. As in football, where opponents watch film to try to find weaknesses to exploit them, 20 years of operations in the Middle East have given great powers a lot of valuable game film to roll right into their weapons development. SCO's response to this is to do what football teams do. Great teams often find themselves overanalyzed and exploited, but they don't throw away their playbooks. They use this vulnerability and turn it into opportunity by creating trick plays. They start running in their pass formations, passing in their run formations. They re-

imagine their strengths rather than playing to their opponents. Like fashion, we can rejuvenate our military playbook if we can reimagine its strengths: ships, aircraft, submarines, things we're familiar with. If we start using them in unforeseen and unexpected ways, we can hope to buy back some of the competitive edge that we're losing to great powers. SCO was created to do precisely this.

Though our strategy often has advantages of lower cost and rapidity, its core tenet, which is our need to change, is anchored in our greatest advantage of all: experienced operators who can do the unparalleled with today's systems and can rapidly master any unconventional tactic we throw at them. This strategy also will provide healthy connective tissue between our past and future efforts; the past, by keeping taxpayer investments for as viable—viable for as long as possible; and the future, by trying to buy time for these future technologies, future systems, the leap-aheads, to field. Because of this, we were tapped to be a near-term component of the broader offset strategy, and our goal is a simple one: to try to enhance our current deterrence, backed by an arsenal of surprises, using systems that we have today.

Our process for achieving this is, itself, innovative, because it flows in reverse from the normal one, from operational needs to systems—actually, from systems to operational needs, rather than vice versa. Living within the constraints of existing hardware and software focuses ideas early on. It encourages cost domain thinking, and necessitates close partnerships with the services to pull off these high-risk prototypes. In 3 and a half years of practice, we've done 23 capabilities, working with the services. Six of them will transition by the end of this year. None have failed to transition, thus far.

These projects, which are really our versions of trick plays, take on one of three forms: repurposing a system for a new mission it wasn't designed to do; integrating systems into a team that can perform the function together, but not separately; and including or incorporating enabling commercial technology. I'm sure we'll cover some examples today, but let me highlight three of them:

Unconventional weapons. Standard Missile 6 was originally designed to defend our ships. We've partnered with the Navy to give it an offensive antiship role. You can also do unconventional defense. Army howitzers, Navy projectiles, Air Force radars weren't designed to be a defensive system, but we're partnering to Frankenstein these into a low-cost supersonic missile defense shield.

Could also do unconventional teams, or kill chains. Stealth fighters were originally designed to use their organic weapons. We're partnering with the Air Force to team them with large standoff arsenal planes so that they don't have to go land and resupply during a fight.

Our third i-program is taking this even further, connecting disparate sensors and shooters from across the joint force.

The rest and best of our details necessarily remain classified, but I hope these few examples give you a sense of how broad the applications could be. We should really let no facet of future conflict be predictable or be as it seems.

As one of the bellwethers for the return to great-power competition, I'm pleased say that SCO is making significant progress in

making current systems count towards a future that's shaped by us, and not for us. I really appreciate your interest in this topic, appreciate this hearing today. I look forward to any questions you might have.

[The prepared statement of Dr. Roper follows:]

PREPARED STATEMENT BY DR. WILLIAM B. ROPER. JR.

Chairman Fischer, Ranking Member Nelson, and Members of the Subcommittee, thank you for the opportunity to testify before you today on this important topic. I am Will Roper, Director of the Strategic Capabilities Office, also known as SCO. It is an honor to be here with esteemed colleagues from the research and development arm of the Department who strive each day to maintain our technology edge against a world of threats. As these threats fill the vast space between non-state terrorism and great power competition, the Department's Third Offset Strategy is returning greater focus to highly-sophisticated adversaries. Recently created in 2012, SCO is the near-term component of this broader strategy, so I would like to share our framing of immediate challenges; process for prototyping solutions; partnerships with the Services, Agencies, and Intelligence Community; and examples of our ongoing work. This will be the focus of my remarks today.

UNDERSTANDING THE CHALLENGE: AN INSTRUCTIVE ANALOGY

Our national security environment is one of complexity—the problems we face are intricate, interconnected, and difficult to simplify. In addition to the all-too-familiar threats of violent extremism, nuclear proliferation, and malign influences in the Middle East, the United States now faces a rising China and revanchist Russia, both challenging international laws and national sovereignty. These concerns span a world that is changing rapidly due to commercial technologies connecting us— and the things in our lives—more quickly and inextricably than ever before. Though challenges themselves are not new to the Defense Department, this rate of change is. It will affect all aspects of our national security, including our return to great power competition.

Though daunting in many respects, we interpret our immediate challenge via a simple, but instructive, analogy: that the U.S. military is akin to a football team running a successful playbook, but for too long. As in football where opponents watch film to find weaknesses, our decades of operations in the Middle East have provided valuable "game film" for rising powers to study and exploit in their weapons and strategy development. Though we still have the most dominant military of earth, we will not remain so if we continue running our 20th-century playbook indefinitely. We must change; the question is: "How?".

SCO's answer is to do what football teams do: great teams often find themselves over-analyzed and exploited, but they do not throw out their old playbooks. They turn this vulnerability into opportunity by creating trick plays: running in pass formations, passing in run formations, reimagining their strengths rather than playing to opponents'. In like fashion, we can rejuvenate our military playbook by reimagining its strengths—ships, subs, aircraft, vehicles, etc.—using them in unforeseen, and hopefully uncontested, ways. The SCO was created over three years ago by Secretary Carter to do precisely this. Since then, we have developed capability partnerships with every Service, four Combatant Commands, and the Intelligence Community—opportunities for implementation are everywhere. Though this strategy often has advantages of lower cost and rapidity, its core tenet—our Department's need for change—is anchored in a greater advantage: our experienced operators, who can do the unparalleled with today's systems and rapidly master unconventional tactics. As in football, it is people—not plays—that ultimately win the game. This strategy also provides healthy connective tissue between our past and future efforts: the past, by keeping taxpayer investments viable for as long as possible; the future, by buying additional time for new technologies to field. Because of this, SCO is the near-term element of the broader Third Offset; our goal, to enhance deterrence backed by an arsenal of surprises and sleights of war using systems we have today.

Striking the balance between deterrence and warfighting is the one place our football analogy breaks down. There is no deterrence in football; teams show up to play regardless of skill differential. Because of this, surprises are never revealed prior to games, but the military must fulfill two competing roles: war reserves to win conflict and deterrence reserves to avoid it altogether. These latter "psychological salvos"—where capabilities are unveiled to change calculus and deter aggression—must be carefully and strategically analyzed to maintain a balanced stockpile for

peace and war. Aiding this is SCO's second mission, and to that end, most of our capability details remain classified. However, I look forward to sharing some selected examples today, as well as our process for creating them.

SCO INNOVATION PROCESS

Our innovation process is, itself, innovative because it flows in reverse: from existing systems to operational needs rather than operational needs to future systems. Living within the constraints of existing hardware and software focuses ideas, encourages joint cross-domain thinking, and necessitates partnerships between SCO and system owners—namely Services, Agencies, and the Intelligence Community—to prototype and prove out concepts before buying them in bulk. In three and half years of practice, SCO has produced 15 projects containing 23 capabilities, with a total of six transitioning by the end of this year, and none failing transition thus far. Our fiscal year 2017 Budget of $902 million includes 36 percent for Navy projects, 24 percent for Air Force, 18 percent for Army, and 22 percent for other institutions. As I will discuss momentarily, we partner with these organizations to execute projects, but several other process attributes are worth highlighting:

- **Creative Imperative:** We strive for five to six strategic capability alternatives in each budget cycle. This maintains our healthy sense of near-term creative urgency as we tackle long-term problems.
- **Creativity Constraints:** Constraints imposed by existing government and commercial hardware and software (e.g. size, weight, power) structure our innovation and provide clear termination criteria. This prevents endless meandering of projects and maximizes the chance of successful transition to programs of record.
- **Cross-Cutting, Good-Enough Solutions:** Squeezing the full potential out of current systems forces us to look orthogonally across Service, Mission, Classification, and Title divides; many of our projects integrate disparate capabilities into hybridized joint solutions. Because speed of response is a key metric, we also explore partial solutions that provide earlier or cheaper alternatives to Department leadership.
- **Rapid Prototyping:** Because SCO repurposes systems for new missions, our concepts are high risk until demonstrated, even though the systems, themselves, may be mature. By funding two- to four-year prototyping efforts inside existing Service program offices, we prepare for future transition without prematurely creating programs before cost and performance are understood. Executing inside existing program offices is a significant force multiplier for our staff, allowing a small, agile team to kick-start many simultaneous projects.
- **Strategic Partnerships:** Our partnerships with Services and Defense Agencies, Combatant Commands, and the Intelligence Community are the true secret to our success; we are simply a hub that allows these important spokes to turn differently.
- *Services and Defense Agencies:* All of the systems we reinvent are owned by Services and Agencies; as such, we cannot explore new concepts without their unique engineering and programmatic expertise. SCO partnerships now span the Air Force, Army, Navy, Marine Corp, and the Missile Defense Agency.
- *Combatant Commands:* Because our solution process is rapid, U.S. Pacific Command and U.S. European Command created local SCO teams to be our theater umbilicals, ensuring our ideas target their most-difficult challenges. This partnership is essential to our success, and we are excited to initiate new efforts with U.S. Strategic Command and U.S. Special Operations Command this year.
- *Intelligence Community:* SCO is a voracious consumer of intelligence; it is vital to our understanding of adversaries and opportunities associated with them. Because the information we covet must be synthesized across multiple topics and disciplines, we have forged close bonds with the Intelligence Community, turning their insights into new concepts.

When applied to the broad U.S. catalog of systems, this process is evolving our immediate power projection playbook via three mechanisms: (i) repurposing systems for new missions, (ii) integrating systems into synergistic teams, and (iii) incorporating enabling commercial technology.

I. REPURPOSING SYSTEMS FOR NEW MISSIONS

Modifying systems for new missions, a practice likely to become easier as designs become open and payloads, modular, has potential benefits of lower cost and faster development, but it also provides an additional bonus—rapid force structure—whenever modifications can be retrofit to current inventories en masse. Because inventory numbers are an important component of peacetime posture, achieving them

rapidly makes this approach highly appealing whenever possible. Some examples of ongoing SCO projects include:

- **Anti-Ship Standard Missile-6 (SM–6):** SM–6 was developed in the early 2000s for air and missile defense of ships. By modifying its software, SCO and the Navy successfully demonstrated its anti-ship ability, giving the Navy the option of switch-hitting the 600+ missiles in its fiscal year 2017 Budget between offense and defense.
- **Maritime Tomahawk:** Tomahawk has been a perennial ship and submarine weapon since the 1980s, but primarily for land targets. Partnering with the Navy on advanced maritime targeting as part of our Strike-Ex project, we transitioned another dual-threat weapon option into the Navy's fiscal year 2017 Budget.
- **Army Tactical Missile Systems (ATACMS) Upgrades:** Options to upgrade the Army's ATACMS missile are also part of our Strike-Ex program. Because the modifications are higher risk than Maritime Tomahawk's, we will team with the Army to build and demonstrate an operational prototype, giving the Army multiple options for next-generation fires.
- **Hypervelocity Guns:** The Army's 155mm Paladin and Navy's Five-inch guns are relatively unchanged since their development in the 1990s. By leveraging projectiles from the electromagnetic railgun program and incorporating advanced composite materials, our joint team is prototyping a "supersonic shield" potentially capable of low-cost missile defense and long-range fires. In fact, a record-breaking, high-speed shot from a howitzer was conducted earlier this year.
- **Ground-Based Fighter Radars:** The Air Force's F–15 Eagle radar was designed in the 1970s and continually modernized into the 2000s. Partnering with the Missile Defense Agency, SCO is prototyping a ground-based variant to protect forward operating bases from dense missile raids, providing a mobile sensor counterpart to hypervelocity guns.
- **Advanced MK–48 Torpedo:** The MK–48 was designed in the 1960s as the Navy's heavyweight torpedo and has been successively upgraded ever since. As the torpedo reenters production, we are partnering with the Navy to build a higher-risk, higher-payoff variant with advanced propulsion, modular payloads, and classified capabilities, enabling this undersea workhorse to go further and do more.

II. INTEGRATING SYSTEMS INTO SYNERGISTIC TEAMS

Teams of systems can survive—and even thrive—in contested environments where individuals, alone, would fail. This is simply due to separating, and then specializing, responsibilities amongst multiple team members as opposed to relying solely on super-star systems. Some of our most successful teams are architected across Service and Agency lines, as well as the Department's classified programs. Some examples include:

- **Arsenal Plane:** Stealth fighters are designed for enemy penetration but at the expense of weapons capacity. By teaming them with standoff Arsenal Planes, these forward scouts can continue to put lethal eyes on target without landing to resupply their weapons. Partnering with the Air Force, SCO will build and test an operational prototype by fiscal year 2020, giving the Air Force a completely new way to extend air power.
- **Third Eye:** Kill chains—the series of steps between finding and finishing targets—can be defeated by denying a single link. Our Third Eye program is working with multiple Services to create resilient "kill webs" where sensors and shooters are increasingly interconnected. Having already teamed disparate assets in live-fire demonstrations, this program should increase the difficulty of denying joint operations.
- **Sea Mob:** Navy ships are designed to carry high-value sensors and weapons—as well our sailors—making them critical to protect during combat. By also making them motherships for small swarming boats, the resulting team can surveil dangerous areas without putting sailors in harm's way. Partnering with the Navy, SCO is building commercially-based kits to convert existing boats into autonomous "sea mobs." In fact, we recently conducted a successful 800km transit using an 11-m Rigid Hull Inflatable Boat.

III. INCORPORATING ENABLING COMMERCIAL TECHNOLOGY

The commercial revolution in smart technologies is rapidly changing most facets of the world. This revolution is taking the ordinary things in our lives—refrigerators, thermostats, phones, to name a few; infusing them with compact sensors

and processors; and wrapping them in high-speed networks and cloud-based services. The net result is new, transformational applications, even though most of the underlying hardware—compressors, thermometers, and antennae—do not radically change. Its spillover into national security is accelerating. In a departure from the past decade, the Department must become a fast adopter of external technology to stay on the cutting edge. Though evolving commercial products may not meet all traditional DoD requirements, failure to move at their speed risks our entanglement in the global web of things, but not on our terms. We must envision and embrace smart military systems in order to thrive on this web, and using commercial technology and agile manufacturing to upgrade legacy assets is one way to begin. Some of our examples include:

- **Advanced Navigation:** Legacy air-to-ground weapons—like Small Diameter Bomb and the Joint Direct Attack Munition—use GPS to navigate, making them effective for strikes against terrorists but less so in regions where GPS is denied. Partnering with the Air Force, SCO is prototyping an upgrade kit leveraging commercial, smartphone-class sensors, giving the more than 37,000 weapons in the Air Force's fiscal year 2017 Budget the option for retrofitting smart navigation.
- **Information Common Operating Picture (iCOP):** Commanders use air, ground, and maritime common operating pictures, or COPs, to understand and respond to changing environments. In our ubiquitously-networked world, understanding the information environment—changing sentiment, perspectives, trends, legitimate news, and manufactured propaganda—is increasingly important. Thanks to commercial advances in big data, analytics, and deep learning, barrages of open-source data are now understandable in real time but relatively unexploited by operational commands. Partnering with U.S. Pacific Command and the Marine Corps, SCO has built and tested a prototype information COP—or iCOP—allowing operators to understand the effects of U.S. actions as well as foreign attempts to undermine them. In fact, just last week, we released the first beta test version to support the ongoing U.S.-Philippines Balikatan exercise.
- **Perdix:** Fighters are designed for speed and maneuverability, not loitering over hostile territory. By equipping them with 3D-printed swarming micro-drones, our fighters can now efficiently search hazardous areas without risk to pilots. Partnering with the Air Force, SCO has tested five generations of "swarmbots" out of F–16s and F–18s, including 150 at the Northern Edge exercise in Alaska last year.

The rest and best of our project details must remain classified, but I hope these examples illustrate how widespread applications can be—no facet of future conflict should be as it seems.

CONCLUSION

In conclusion, both our great power challenges and opportunities are great: our challenges, because they require Department-wide change; our opportunities, because they involve some of our greatest strengths—ingenuity, technology, and operational prowess. If we leverage these strengths in concert, a new U.S. power projection playbook—one that undercuts attempts to exploit our predictability— can commence with systems we have today and continue as advanced systems field in future. Sustaining momentum on this playbook will require taking the long view while maintaining a sense of urgency today. As one of the bellwethers for the return to great power competition, I am pleased to say that SCO is making significant progress in making today count towards a future shaped by us, not for us. I hope you will support the President's 2017 Budget as we seek to sustain momentum inside the broader, Department-wide Third Offset.

Thank you, again, for the opportunity to testify today. I am happy to respond to any questions.

Senator FISCHER. Thank you very much.

Again, welcome to all of you. I think this is going to be a fascinating hearing.

Secretary Welby, if I could begin, a factsheet that was provided by the OSD [Office of the Secretary of Defense] states that realizing the third offset strategy will require the right combination of bottom-up innovation and experimentation to push the technical and operational envelope and senior-leader top-down direction to

initiate major programmatic, operational, and organizational change. I'd like to ask you about that last part. What the major programmatic, operational, and organization changes are being made as part of that offset strategy or—basically, what's the Department proposing to do differently in this budget request with regards to the offset strategy?

Mr. WELBY. Chairman, the—if I—if you look to the investments that are in the 2017 budget, there are some very significant muscle movements that you can see in that budget. I'll point to a couple of key technology areas first: a major reinvestment in hypersonic capabilities, an increase in the number of systems that we're carrying to the range in the hypersonics weapon regime by 50 percent, an increase in the investment in our ranges to increase our hypersonic capabilities, and investments in our laboratories in industry to take those systems from being technology demonstrators to being no-kidding weapons that we could actually think about deploying with our force.

In the undersea arena, you see a significant reinvestment in unmanned undersea vehicles as an augment to our manned undersea force as a significant force multiplier, as a key experimental asset for the future of the Navy. You can see within that budget significant investments looking at a variety of novel weapons concepts that might have significant application to the future force.

Over the last year, you've seen the Department really open its aperture to all sources of potential innovation, to include engaging the defense industrial base, in terms of ensuring transparency on their IRAD investments so we can work forward—march forward together collectively against these kind of challenges, understanding what they're investing in, understanding what we're investing in. You've seen the Department engaging the innovative commercial sector through outreach efforts like—EWACS on the West Coast and the Secretary's continuous engagement with the commercial sector, trying to find ways to bring both people and ideas back into—reinvigorate our activities.

We are reemphasizing the importance of the DOD laboratories to this initiative. The laboratories in the individual services and our engagement with partner laboratories in DOE, as well as innovation engines that can help drive the future of the Department. We are emphasizing the need for speed from laboratory to fleet. The recognition that there's enormous innovation that has continued within the laboratories even while the Department may have reduced its focus on fielding that capability, but that store of novel ideas needs to be taken to the test ranges and experimented with.

Finally, I want to point to the focus on prototyping and experimentation. When you look to the second offset that occurred in the 1980s, the ideas for that—for those technologies emerged in the mid-1970s. In 1979 and 1980, the Department conducted a series of major experiments on the western ranges, where we put together precision weapons, long-range ISR platforms, the first flights of what became Joint STARS, the first systems of what became the Army ATACAMS, early flights of Apache Longbow, and many other capabilities. Across the range, in the classified portfolio at that time, we were flying the F–117 and experimenting with the emergence of real stealth capabilities. That incredible innovative energy

that occurred at the operational level, not simply doing laboratory experiments, but putting it into the hands of operators and letting them understand how they might fight those capabilities, is what enabled the set of capabilities that in the 1980s, as the Reagan defense buildup, we didn't buy the same things; we bought an entire new generation of capabilities. But, we didn't buy it blind. We bought it with the knowledge that came from those exercises. The Department is now preparing for another series of investments in prototyping and experimentation. We want to get our ranges busy again. We want to get new systems out on those ranges. Whether we procure them all, or not, we want to learn from those systems and inform what we need in the future.

Senator FISCHER. Right.

Mr. WELBY.—making the Department smart for its future choices.

Senator FISCHER. In the budget's 3.6 billion, funding specifically related to the offset strategy, can you provide the committee with a breakdown of this funding? Will you get that information to us, please, by programs?

Mr. WELBY. I'd be happy to provide you detail. Some of those remain classified.

Senator FISCHER. You've mentioned a lot of them, but can you get us the detail, by program, for that——

Mr. WELBY. I'd be happy to do that.

Senator FISCHER.—for that spending? Thank you.

[The information referred to follows:]

Within the Secretary of Defense's written statement before the Senate Armed Services Committee, Secretary Carter discussed the Third Offset Strategy for investing in and operationalizing our security by leveraging advances in cyber, space, electronic warfare, biotechnology, artificial intelligence and other areas. A classified list representing the Department's investment in the Third Offset Strategy will be sent separately.

Senator FISCHER. Also, we're going to have a change of administration in January, and what sort of things do you want to have accomplished by that time to demonstrate that this effort is on the right path?

Mr. WELBY. I'm sure that any transition team that—for any administration to come is going to face the same set of challenges that we face today. The pull here is the recognition of the need to address U.S. strengths in a future competitive national security environment. That's an external pull. This is not—while this is Dr. Carter's initiative, it's the Deputy's initiative, while I'm trying to drive this, it's not driven by personality; it's driven by the Nation's need to refresh our technology——

Senator FISCHER. Right. How—and what are you going to point to that you've accomplished? I think you have a lot of support on this committee. We understand the importance of where we're headed with technology in order to change warfighting so that we continue to defend this country. How are we going to make sure this moves forward?

Mr. WELBY. We're not going to stop for the next 9 months of running to make sure that the next administration has a running start to these problems. We've completed, recently, the Long-Range Research and Development Planning Program, an 18-month study

that looked at details and laid out a series of opportunities for the Nation, going forward. All that material, we're trying to harness across the laboratory complex today to make sure we're ready for what comes next. I think that we—that this budget and the initiatives we have ongoing prepare for that future in an important way and lay ground for the next administration.

Senator FISCHER. Okay. Thank you very much.

Senator Nelson.

Senator NELSON. Thank you, Madam Chairman.

Mr. Secretary, thank you for your public service.

Dr. Prabhakar and Dr. Roper, given the fact that I've already spent a great deal of time with both of you, asking a lot of questions, and given the fact that our enemies' spies are listening to what you say today, I really don't want to ask you any questions in an open session. I would invite the members of this subcommittee to get in a classified setting to figure out some of the gee-whiz stuff that these folks are doing. But, since it's an open setting, I'm just going to leave it to you. Say whatever you'd like. That's all I'm going to say.

Dr. PRABHAKAR. Well, it's hard to resist an invitation like that. Thank you very much, Senator Nelson.

You know, I think, absolutely, the details of the programs that we think can be very impactful here do need to remain classified. We're happy to provide classified briefing to any of you who would like to come do that. We'd be very pleased to do it.

I actually think the most interesting aspect of what we're all working on in the third offset strategy and these technologies—really, the question, as a technologist, that I see is—in a world in which we no longer get to have all the toys and nobody else gets to have any technology capability—that was an unusual period, after the second World War, when we had that enormous technological advantage over the rest of the world—that's not the world anymore, and we all know that technology, wherever it originates, it flows. We know that many other countries now have amazing engineers and scientists and laboratory facilities. All of that is really good for the world. It's actually—it's elevated living standards. It's connected us in new ways. Most of that is good news.

The challenge, of course, that this is all about is the fact that we still have to come up with a technological edge for national security, despite a more and more level playing field of initial technologies. I actually think the success here is going to come from something that's a deeply American way of approaching the problem. I—you know, a lot of what we do at DARPA is about this idea that we're going to—we're willing to take risk to reach for high payoff, and we are willing to try things that might fail. But, in combining these commercial technologies, accessing leading-edge commercial technology and then combining it with places where we do have an edge and where we can protect the technology, at least for some period of time, if we can learn to do that and move faster than anyone else around the planet, I'm actually quite confident that we are still going to be able to win in this competition.

Dr. ROPER. Senator Nelson, I think it's an important point that you raise, is that a lot of the technology edges that we're going to develop are developing, and will be moving to testing very soon, are

surprises. They're things that are intended to deal us back into the game. They're intended to project power in different ways that we haven't before. There's going to be a very difficult calculus that we're starting to begin as part of the third offset effort, which is, Is it a surprise that we want to tuck behind our locked doors and save to be able to win a war? We have to be able to so that. That's our job, as the Department. But, if we were to put every surprise that we develop behind the door, we would be biasing our portfolio towards a go-to-war posture, as opposed to a deterrent posture.

One of the challenges we're going to have is, we're back into a deterrent mode, as the Department. But, as opposed to the Cold War, it's not a monopolar deterrent posture. We've got to do it in a bipolar way. Must be able to think about China and Russia while we continue to focus on the Middle East, continue to focus on North Korea.

There's no easy math for deciding whether or not to show a capability, or not. We've started putting some of our capabilities public now from Strategic Capabilities Office. We have had almost no public face for 3 and a half years. As you were able to see yesterday, quite a lot of our portfolio is behind the door, and deeply so. But, if we put everything there, we'll be doing the country a disservice, in the long run.

Senator NELSON. Thanks.

Thanks, Madam Chair. That's it.

Senator FISCHER. Thank you.

Senator Tillis.

Senator TILLIS. Thank you, Madam Chair.

Thank you all for being here. I look forward to future briefings in a classified setting. I appreciate the work that you all have done.

I'm going to go to the more, maybe, boring side of the equation, and it has to do with actually getting good ideas fielded and in use. That gets to procurement, acquisition, specification, partnering with the private sector, where it's appropriate. Can you give me some idea of where you all think we are and where we need to focus, perhaps even as a matter of public policy changes to remove constraints and try and compress idea-to-fielding timelines over what we have today?

We'll start with the Secretary.

Mr. WELBY. Senator, I—we're emphasizing, in every engagement, speed. In—as we enter a more competitive future, where we're all drawing off a globally accessible technology base, we're going to need to close our acquisition OODA [Observe, Orient, Diode and Act] loop, if you will, faster than our adversaries. We have to turn quickly. We need to think about time to market, like folks do in the commercial sector. We've been engaging our laboratories in a discussion about how quickly we can move ideas from our tech base to the field. There's no way to rush discovery. I mean, science takes the time it takes. But, we ought to be thinking, even as we're exploring new areas, about that application and how we can prime the pump for that application.

On the acquisition side, we've been challenging ourselves to be able to move faster, especially at that cutting edge of new technologies. We've been looking for ways to be able to engage new partners in timelines that might be measured in weeks, rather

than months and often a year, to contract. Especially since we're dealing with fast-moving technology areas, people aren't willing to wait for a year for the Department to get involved. It—there's no return on that. They'd rather focus on commercial-sector engagements.

We've been exploring new means to much more rapidly get—bring folks on to contract, to use competitive vehicles in commercial acquisition, and to think about new ways to bring technology into platforms and systems, leveraging modular architecture approaches, for or persistent architecture approaches for example, be able to plug-and-play technologies into our existing systems to speed the upgrade cycle.

I think that, through the S&T initiatives, through the formal acquisition initiatives, the Department's better buying power, 3.0 activities, which have a large focus on modularity and tech insertion, I think that we are trying to move much faster as we go forward.

I think, in the future, we won't see 30-year development programs in anything. Adversaries will have countermeasures prepared for a decade before we field something, if that's the case. We need to up our game, in terms of speed.

I don't know if anybody else has anything you want to add.

Dr. PRABHAKAR. I would just add, first of all, that, in the work that we do at DARPA, of course, we live in the science and technology part of the portfolio. I want to be very clear that our task in developing technologies is not as onerous as procuring systems that our warfighters, you know, need to be confident in and they can trust under extreme circumstances.

Having said that, we've had the opportunity, over the last many decades now at DARPA, to experiment with some novel procurement mechanisms that your committee invented and authorized over numbers of years. One example is other transactions authority. That's an example of a capability that we and others in the Department have. We've used it to great effect, essentially to do business with companies on commercial terms. It—we comply with the law, but we are able, under other transactions authority, to set aside the Federal acquisition regulations along—and part of that, of course, means that we—we're not forcing companies to do government accounting systems and to have that burden. Especially for commercial companies, it's a particularly good way to be able to move faster, and sometimes it just enables them to be willing to do business with us in the first place.

I think there are some practices like that, that I think we've been able to pilot that we hope can be expanded.

Senator TILLIS. Dr. Roper?

Dr. ROPER. Senator, I think, you know, our piece within SCO is really trying to complete the circle on the acquisition process. We currently flow from an operational need to a future system that we field. As Secretary Welby pointed out, there are lots of efforts underway to try to speed that cycle up. But, wherever we can find ways to take things that have come out of that pipeline and bring them back to the beginning, solve additional operational needs, whether they're within that service or outside of it, then we're producing lower-cost options that will allow that service to build budgets, where there's more innovation in them.

The biggest issue that service programmers bring up to me is that they want to innovate. I can attest, from the programs we do with them, there is incredible innovation potential in the services. It's resident in every partnership we build with them. When they build a budget, if their readiness, the fight-tonight capability, is put at risk, the first thing that has to go is the innovation side of it. Wherever we can buy them flexibility and breathing room to keep that innovation in play, we're doing a good thing, not just for them, but for the country. We've got to make stuff that our taxpayers have already invested in do more and stay viable longer if we're going to free up funds to go for the big-win technology leapaheads.

Senator TILLIS. Yeah. I think your point about turning defensive weapons into—transforming them into offensive capabilities, and vice versa, is very good. The—because I'm assuming that the time to field that capability is far less than an all-new platform, and that's why it's important that we squeeze everything we can.

In my remaining time—you touched on something, Dr. Roper, that I was going to ask. I know that Secretary Carter has announced a program engaging—trying to expand our engagement with Silicon Valley in partnering with some of the major tech firms. But, in my experience—I'm from North Carolina, and down in and around Fort Bragg, there's a lot of small businesses that come from people who have battlefield experience. They're coming out, they're perfecting things that have extraordinary potential, more often than not because they had to put the first iteration together with duct tape and Super Glue, they had to use commercially available products.

To what extent does your area of focus focus on sometimes—you know, sometimes you need $100 saddle because you've got $100 horse. But, sometimes you've got a $10-horse problem you want solve, which is what I've seen a lot of these folks doing down here. It seems like every once in a while, DOD wants to put $100 saddle even on a $10 horse. How are we getting some of that applied small-business feedback into the mix as a key part of the innovation loop?

Mr. WELBY. Maybe two quick responses.

First is that I'm frustrated that a lot of the discussion around engaging the innovation ecosystem has used Silicon Valley as the term of art, but, quite frankly, there is remarkable work going on from Boston to Austin to Silicon Valley, Research Triangle—I've gotten right back to that one——

[Laughter.]

Mr. WELBY. But—and I'll touch everybody in the room—but, look, it's—and I think that there's really interesting things going on in the small-business side. The Direct to Phase II piece, for example, on our civil work, is now—we've now identified new mechanisms by which we can reach out and touch small businesses, not just at the hey-do-a-study-for-us scale, but the no-kidding-rapidly-moving-to-a-prototype-so-we-can-try-it—to get at those folks who have near-immediate solutions and put them into test and evaluation.

I—as the Secretary has pointed out, the Department needs to focus on porosity, our openness to ideas, wherever they come. We

need to take the blinders off and not just to be—look to the defense industrial base as the only source. It's an important source, but it's not the only source of ideas. We're trying to reach out anywhere we can.

Senator FISCHER. Thank you, Senator Tillis.

Senator Heinrich.

Senator HEINRICH. Secretary Welby, this committee, last year, showed really strong bipartisan support for directed energy weapon systems in the NDAA, and we asked that the Department look at that as part of the third offset approach. How much of the 100 million provided by Congress last year within this effort has gone towards directed energy?

Mr. WELBY. Thank you, Senator. We have not—the language in the report last year for the offset technology initiative requested that we go out and survey the services, looking for competitive ideas, survey the COCOMs, looking for ideas. We have completed that. I have—we have a stack of proposals that we're going through now, and we're allocating resources against them, expect to be able to provide the details of what we fund from that list here in the next week or two. I am certain that, in that stack of proposals, there will be directed energy. They are at—they are near the top of the list of things we want to do. I'm expecting that, of the list of things, order of 20 percent would be focused on directed energy. But, we're still trying to finalize both the list and ensuring we've got the right budgets for those projects. We want to make sure that the things we do fund with that activity are robust and are not underfunded.

Senator HEINRICH. I agree wholeheartedly with that approach. Just to sort of follow up on that, I'm curious about—it seems to me that this technology—directed energy, in particular—could be one of those places where we really do provide an offset. It's—doesn't have a peer-relatable equivalent in other military spaces. I actually introduced legislation this morning with Senator Inhofe to look at granting rapid acquisition authorities for directed-energy weapon systems. I'm curious—and this could be for any of you, actually—in your opinions, is this an area where the Department is moving fast enough to transition the technology, or are we sort of stuck in an endless R&D [research and development] loop, where it's always easier to chase the perfect instead of field what is quite applicable today?

Mr. WELBY. Senator, I participated in the Directed Energy Professional Society Symposium at the Pentagon today. We have over——

Senator HEINRICH. Good timing.

Mr. WELBY.—we have 20 folks sitting in the courtyard of the Pentagon today, demonstrating next-generation laser capabilities and high-power microwave capabilities. As you know, I've spent a good portion of my career working in this space. I remain convinced that we are now at the point where we're moving out of the labs and into application space with those kind of systems. I saw some remarkable technology on display today. We're encouraging folks to think about how we can accelerate those into real applications.

I think that directed energy has suffered from being—from always being just 25 years off. I think we're now not 25 years off.

I think there are real applications in the near term, and opportunities to grow those applications in the mid-term. I'm excited about the space.

Senator HEINRICH. I appreciate you mentioning microwaves to somebody who used to work at Air Force Research Labs on microwaves as well as lasers. Sometimes we forget that application. When you look at things like CHAMP and other applications, it is substantial.

For, really, any of you, one of the things I'm concerned about—with the possible exception of DARPA, actually—I think there's been a real risk averseness, generally, within the R&D approach of the Department of Defense, at times. In looking at our nuclear labs, one of the things that has worked there to get around an obvious—you know, it's easy to be risk-inverse in this environment. You've seen huge advances, for example, on—in energy, with things like solar technology, prices plummeting, but one Solyndra can become a political issue. It's easy to accept that same sort of mindset within defense research.

LDRD, laboratory-directed research and development, has been one of the places where, within the nuclear labs, it really has seemed to be a high-risk but high-reward endeavor that is incredibly valuable, for one, in attracting the right talent into the pool in the first place.

I'm curious how the Department views that balance between risk and reward, and what steps are needed to ensure that researchers have the leeway and the flexibility to pursue something that is truly innovative.

Mr. WELBY. Senator, across the laboratory complex, we have to recognize that there's a number of constituents we try to service.

Senator HEINRICH. Sure.

Mr. WELBY. There are near-term transitions into programs of record. There are those medium-term capabilities that seek to be able to demonstrate capability to drive the next program of record. Then there are activities that are further to the left that are really trying to be disruptive. We have been focusing the laboratories, over the last year, on trying to be explicit about how we manage those three portfolios, how we think about those things that are near-term and in service of programs of record, how we think about those things that are shaping, kind of, the next program, and those things that are much more foundational.

Just a couple of examples of things that we're doing. We—in—across laboratories, we've now created resources available to the laboratories out of the OSD-level budgets, where we've asked the laboratories to compete—to compete on ideas for who has the greatest game-changer. We've offered to amplify service budgets in areas where we can see that real impact. Internal competitions, right? But, to get teams challenged and thinking about competing with each other, kind of, across laboratory complexes.

The trick is, of course, at the end, we tend to team those folks together to get all the best and brightest of the ideas across, because we're really in one game, but it's encouraged folks to think differently.

Within the services, as well, each of the services has been trying to drive more innovation through their own long-term S&T pools. I'm very excited about how that's taking place.

Senator HEINRICH. Doctor?

Dr. PRABHAKAR. Maybe just to tag onto that. DARPA's very much in the high-risk, high-payoff business.

Senator HEINRICH. Sure.

Dr. PRABHAKAR. I never take for granted the room that we get to do that, starting with our bosses, starting with Steve, but all the way up to the Secretary, and definitely from Congress. That—you know, I think—I feel very privileged to lead an organization that has delivered on that mission for long enough that you all give us rope. All we have to do is come up with the next revolutionary capability.

But, within the agency, as well, I don't take for granted how we nurture that. Steve's exactly right that, you know, you do need to manage a high-risk organization in a very different way.

Senator HEINRICH. Right.

Dr. PRABHAKAR. But, continually nurturing that culture, making sure that our business processes reflect the mission and that culture, it's everything from the conversations I have with my program managers when I walk by their offices to the way that they work to get their programs approved. I think it's something that needs concerted focus, but——

Senator HEINRICH. Yeah.

Dr. PRABHAKAR.—I think we know how to do it, and I think it's a—it is an essential ingredient in the mix.

Senator HEINRICH. Great.

Senator FISCHER. Thank you, Senator Heinrich.

Senator Manchin.

Senator MANCHIN. Thank you, Madam Chairman.

Thank you all.

I'd like to ask—I think this is to Mr. Welby, if I may, Secretary. Secretary Carter recently announced a major initiative for outreach to high-tech companies in Silicon Valley, as you know. DOD has—also has a small business innovation research program that taps into technology innovations from all around the country. The SBIR program helps small business compete to bring value-added products and services to our military. This program is extremely helpful for the economy of West Virginia, because we have a corridor which really participates in that. I'd like to ask, How are we coordinating efforts of engaging these small companies to work with DOE? My reason for saying that, some of them get into the procurement process, they have to tag along with a large major in order to get any pittance of a little bit of work and become subservient to that. Is there any method of getting them directly into the flow, if you will?

Mr. WELBY. Senator, I also highly value the small business innovative research activities. I think that my experience working with companies in the small business innovative research area has allowed them to grow rapidly and actually contribute in important ways to major——

Senator MANCHIN. Right.

Mr. WELBY.—defense acquisition programs.

I mentioned earlier the Direct to Phase II activities, which all us to make initial grants to companies at a much larger scale than simply, "Here's 100K to kind of—to go develop a proposal," the very early study grants that SBIR has typically worked through to cut a year off the time to get people up to scale and to be really playing with real—at real working levels, up to a million dollars for an initial grant, which is a lot for a small company, initial space.

The—one thing I should—I want to point out about the kind of engagements we have with this Defense Innovation Unit Experimental [DIUX], for example, is, again, it's not geographically tied. We want them to be engaged over a broader portion of the country. We've not given them acquisition authority. That organization is really intended to help shepherd small companies through the process, make introductions to help them understand the process, to, if you will, act as a shepherd to kind of help them work their way through the system. We're experimenting with that idea that getting small companies, getting the kind of core innovation drivers that we see in small business through our system is a contact sport and requires significant help, folks who speak their language, who understand the innovation ecosystem, understand companies' commercial ambitions, as well, and can still talk DOD to them. We're trying to understand how that works. That's the experimental portion of DIUX. It really is an experiment to see how we can gauge better.

But, we are trying to find new opportunities to introduce small-business work throughout our enterprise. We're continuously reinforcing our small-business participation objectives in all of our programs.

Senator MANCHIN. You all go out and solicit this? I mean, go talk to some of the areas, where they're—not just Silicon Valley, but, I mean, other——

Mr. WELBY. I do. Our team does. We are thinking hard about——

Senator MANCHIN. Can we get you down to West Virginia? Can I get you down?

Mr. WELBY. Sir, I'd love the opportunity to come visit. I'd——

Senator MANCHIN. Hey, Rick, sign him up.

[Laughter.]

Senator MANCHIN. We'll get you down there. It's not that far away.

To Dr. Prabhakar, one of the joys of being a Senator is being able to nominate some of the best and brightest to our military academies. It's really, really something special, when you see these young, bright people coming from all over the country and getting this opportunity. I would ask—DARPA regularly engages with civilian universities, which we're very appreciative of that, too, for the advanced research efforts. How—what's the percentage of how you all engage with our military academies versus the private? Because we know it's going to be used—and I'm understanding that, basically, they do a senior project, all the military academies, to participate in cutting-edge defense research. These are people not only that are participating, but going to be fulfilling them. Do you put more of an emphasis on academies than you do private?

Dr. PRABHAKAR. Senator, our starting point with everything that we do at DARPA is to go out and find the technical talents that are going to have the ideas and the ability to go execute on them. Through that, we work with universities of all sorts, but also, of course, a lot with companies of all——

Senator MANCHIN. You all pay——

Dr. PRABHAKAR.—sizes.

Senator MANCHIN. You pay, right?

Dr. PRABHAKAR. Our—we fund those projects and those companies. We're actually only——

Senator MANCHIN. You're already funding—we already fund the military academies. We already paid once.

Dr. PRABHAKAR. I think it's a great question you've raised, because I think about the people who are attending those military academies——

Senator MANCHIN. Yeah.

Dr. PRABHAKAR.—frequently. They are going to be the warfighters who use the——

Senator MANCHIN. That's exactly right.

Dr. PRABHAKAR.—technologies that we are brewing. We reach out to them in a variety of ways. In recent years, as an example, we conducted a competition among the academies in the cyber arena. That's one, in particular, where the—you know, there's a lot of interest, but also a great need to continue to educate warfighters that are going to be adept in the cyber environment.

Senator MANCHIN. Could I——

Dr. PRABHAKAR.—they are very much part of our community.

Senator MANCHIN. Would it be possible to get a report, basically, on the amount of money that you all do put out in doing these—engaging in these research——

Dr. PRABHAKAR. Yeah, I'd be happy to look into that.

Senator MANCHIN.—versus——

Dr. PRABHAKAR. Just to set your——

Senator MANCHIN.—versus the academies.

Dr. PRABHAKAR. I just—I'd be happy to get you that data.

Just to set your expectation, the amount of research that's done of the sort that we typically fund at the academies is fairly limited, because their focus, of course, is educating these young folks who are going to become our future warfighters. I would be happy to get you that data.

Senator MANCHIN. But, what you're going——

Dr. PRABHAKAR. But, that's now where the research——

Senator MANCHIN.—you're going to——

Dr. PRABHAKAR.—is typically done.

Senator MANCHIN. You're telling me right now, you don't put much in the academies.

Dr. PRABHAKAR. I don't think you'll find a significant amount of money flowing there. But, again——

Senator MANCHIN. Let me ask you this——

Dr. PRABHAKAR.—their role is different——

Senator MANCHIN. Cadets and——

Dr. PRABHAKAR.—from what we do.

Senator MANCHIN.—midshipmen start their senior project, they have—they have to have a senior project.

Dr. PRABHAKAR. Yup.

Senator MANCHIN. Okay? Do they know there is a pathway that they could take something of high cutting-edge, such as what you all are looking for? I mean, to me, I—maybe I'm wrong, I don't know. I just believe that we've got some outstanding—you know, I'm not saying universities—I mean, we have research, WV and all of them.

Dr. PRABHAKAR. Yup.

Senator MANCHIN. But, I'm saying, we already own this. We—this belongs to us. Those are 4- to 5-year employments afterwards, so we know they're going to be the ones who are going to be implementing everything we're doing.

Dr. PRABHAKAR. Yes, I agree that they are an important part. But, again, DARPA'S role——

Senator MANCHIN. I know.

Dr. PRABHAKAR.—is about research; it's not really the education of that part of—you know, that critical part of our workforce.

Senator MANCHIN. I gotcha.

That's—no further questions,

Senator FISCHER. Thank you, Senator Manchin.

I think it's safe to say that the goal of this initiative is to preserve and enhance our technology-based military superiority. That's part of the meaning of the term "offset." We're not going to be fighting our adversaries tank-to-tank anymore. Technology does provide us that advantage and the offset to—with capabilities for others.

Dr. Roper, you know, I'm concerned that we become so reliant upon technology that that reliance can be exploited, and it can be exploited very cheaply, in some instances. I think space is a good example for us to look at in that regard. Our adversaries can jeopardize our constellation for a lot less money than developing new technology for us to build here and take advantage of that. How do you ensure that the greater incorporation of technology doesn't turn into a dependence? How do you ensure that we don't allow our adversaries this opportunity to be able to undermine what we're trying to do in a really—basically, a cheap way?

Dr. Prabhakar, I'd like to ask you that, as well.

Dr. ROPER. Thank you, Senator. It's a great question. I'll address the space component of it, but I'd like to then broaden to the bigger question——

Senator FISCHER. Yes.

Dr. ROPER.—of, you know, where is—where does technology end and other advantages begin?

I think, as indicated by a lot of the discussion this morning, we're moving into a regime where relative technology advantage is going to be lowering amongst the great powers in the world. The United States, China, Russia——

Senator FISCHER. Our adversaries are catching up to us.

Dr. ROPER. Catching up. We're also living in a world where technology is speeding up, so the impact of commercially available technologies is going to be large. It's also going to be available to everyone. This is going to force the Department, as well as our adversaries and competitors—it's going to force us to become fast adapters. When we look at areas where the environment's going to be

contested—and space is one of those—there's obviously the disadvantage of not having the legacy way that we've projected power be something that can be continued into the future, but we'll be moving into a future where there is hope for us. It's very likely that we'll start having distributed space architectures and future where maybe individual satellites are contestable, but the architecture, as a whole, isn't. That'll force us to start using statistics as a metric, where you're not—you can't calculate the reliability of a single thing, but you're doing it in aggregate. That's something very common for many industries. The cellular companies that sell to us are used to having a statistical approach to their availability, as opposed to a singular one.

What I think this means is that warfighting is going to be messy. We're not going to be able to go in and have very simple mathematics and physics help us calculate the margin of battle. Things are going to be constantly changing. Satellites that are available won't be. Networks that are available won't be. If we're wise, we'll have architectures in place where we hop between different assets that are available.

I think that's where we actually get off the stage with our biggest advantage. That's a messy environment. Not every country is going to be able to get their operators ready to deal with it. The greatest advantage we have, and the reason I think we'll pull this offset off, is that we're coming out of 20 years of operational experience that no one in the world can match. We're saying to the world, we're going to change, we're going to go into this messy environment with our eyes open, and we're going to dominate in it. That's based on giving operators, one, the technology to be able to adapt in that environment, but trusting them to be able to use it and master it.

I think the biggest ill that we could do, as a Department, is to have all the shiny bells and whistles in the technology world, which are important, override what's underwriting it, which is our human operator foundation.

Senator FISCHER. Thank you.

Dr. Prabhakar.

Dr. PRABHAKAR. Yeah, I think Will's completely correct with what his—especially his concluding point. I often think about how reliant, even in our civilian lives, we've all become on GPS, where I only will just follow that blue dot or listen to those instructions. That's a great example of needing to remember that technology is a very powerful tool, but it doesn't allow you to suspend judgment. We're seeing some examples where that's really gone wrong.

Technology is, of course, only going to be one component in the solutions that we're talking about here. We very much see part of our job, of course, driving the technology, but also thinking in terms of, How do we make it secure and reliable? Cybersecurity is a very big part of that. We have a significant portfolio that focuses on that.

But, at the end of the day, it really is about how humans use the technology. I think, as we have moved from more of a gadget focus to, "How do you think about winning the war?" it has really driven our thinking to rarely think about the whole system of how humans and machines are going to interact together. That's a much

harder problem and a much richer problem, but I think it's going to be important to getting to solutions that really do work.

Senator FISCHER. Mr. Welby, I've seen a factsheet that was put out by the Department, and it discusses those investments that I believe the Doctor was just talking about, with the human and the machine collaboration that's going on. It states all of these components will be connected to a cyber-hardened human-machine command-and-control network. You know, we're not really good at keeping adversaries out of our networks. Let me rephrase that. We are good at it, at keeping them out, but they still get in. How are we going to have confidence that we have the ability to build this cyber-hardened network? Do you think that the network should come before we think about the pieces that rely upon it? Should we make sure we have the security there before we get the bells and the whistles that depend upon it?

Mr. WELBY. Senator, I believe that there's a real opportunity here to codesign these capabilities in ways we have not in the past. One of the really interesting things that's going on is this notion of autonomous systems, systems that I can give direction to, and that I can have confidence that they're going to have certain behavior and then check back in with me at some future point. That offers a way to think about how systems can actually operate on—even on unreliable networks. By reducing the bandwidth required to, for example, tell the operate system; by having the ability to have systems interact with humans by exception, just as I would with—send a soldier up a hill, call me if you see something that you need assistance with—I can start to think about machines that might be able to do that.

We—we're talking about manned-unmanned teaming and trying to understand how that works, what kind of bandwidth is required, where and when systems need to interact. I think it's very important in scoping the networks required to support those.

We did some recent studies, where we looked at just how little bandwidth was required to ensure control over—in a simulated environment or some notional unmanned-manned system concepts. We were very enthusiastic about the ability to shrink that amount of bandwidth required in very interesting ways. It—the smaller the pipe, the easier it is to protect. We're thinking about very novel ideas in that space.

Senator FISCHER. There's a discussion going on in the Commerce Committee about spectrum, since you're talking about bandwidth. You said you're shrinking bandwidth that's necessary for the Department of Defense. Would you say you don't need all that you have? Put you on the spot here.

Mr. WELBY. Today, I think we need all we have, and more.

Senator FISCHER. You need it all.

Mr. WELBY. We need it all. Particularly for radar is really one of the critical things. Our large-bandwidth sensors are really a challenge. Spectrum auction has caused the Department to have to shift in very complex ways, and we're continuing to work through that. Comma, with my technology hat on, I am very excited about agile spectral use in the future and ways we can start to think about the technologies that will help shift, not just the military sector, but maybe in—on someday, the commercial sector to be much

more efficient users of spectrum. I am enormously excited about the initiatives that DARPA has started here in the last 2 weeks to set up prizes associated with very novel use of the spectrum, an arena to challenge folks to come in with entirely new concepts for agile radio development, and to think about new ways that we can architect our commercial and military systems to be really efficient users locally, regionally, and globally to make the most use of the spectrum we have. The demand for spectrum is only going in one direction. Wide bandwidth applications on the commercial side, wide width applications on the military side are going to grow. But, in the fight, which is what we were talking about a moment ago, we're going to want to be able to—if we lose that spectrum, to still be able to fight through. We think there's very interesting ways we can do that.

If, Arati, you want to say a word about the spectrum challenge.

Dr. PRABHAKAR. You can tell Steve is a DARPA alum, because he summarized our new DARPA program perfectly.

Senator FISCHER. I was going to say, because we have such a truly limited amount—a finite amount of spectrum that's out there, and to find a more efficient way to use it would be beneficial, Of course, for our national security, but also for our businesses that are out there, as well.

Thank you.

Senator Kaine.

Senator KAINE. Thank you, Madam Chair.

I apologize for being late. Was at another subcommittee hearing, so I may ask questions that you've already covered. But, it's good to be with you, and thank you for your service.

I'm interested in the interface between the DOD requirements and commercial requirements in a very—you know, complex commercial environments. Generally, the security requirements of the DOD exceed the commercial space, or will—or, in many ways, is the commercial sector market develop the industry and some of the security ahead of the DOD mean?

Dr. PRABHAKAR. I'll take a stab at that. You know, if you peel apart what DOD needs, in terms of information security, cyber security in particular, we need everything that the commercial sector needs, because we use commercial networks and computers and systems for all of our operations, and we have cybersecurity needs for our very sophisticated electronics and computing that's embedded in every—you know, every missile, every aircraft, every ship, et cetera. I—across DOD, I think we have the challenge of adopting, as quickly as we can, the leading edge of commercial cybertechnologies, and we continue to press—you know, the Department continues to press forward on that. Conversely, in some areas where we are able to drive cybersecurity research because of DOD's embedded computing needs, I think there are places where—and, for example, in some of the DARPA programs, we have focused on this question of, Can you build a cyber retrofit, for example——

Senator KAINE. Yeah.

Dr. PRABHAKAR.—for a system that goes on an unmanned aircraft? We've just had some very good research success in that area. That's an example of research that I think at this point is leading-

edge around the world. Eventually, I think it will become an important part of a better foundation of cybersecurity for DOD systems. But, it's the same technology that will also provide a secure way for the Internet of Things to grow. The Internet of Things is either going to be awesome, if we can figure out security, or it's going to be a nightmare. I think—you know, I think that's an example of a technology area driven for DOD that we can also actually contribute to the broader set of——

Senator KAINE. Sort of—it's a good segue to the follow up question I wanted to ask. If some of the particular requirements we have in the DOD space will really be driven by our own research, then we obviously need to be robust in funding research. But, to the extent that some of it is going to be commercial capacity that we purchased, then that says something about acquisition and the acquisition workforce. As I deal with folks in the, kind of, private sector, they are quite concerned about, Is the acquisition workforce up to the job? They actually really kind of sympathize with an acquisition workforce. They feel like the DOD, and maybe the Federal, generally, acquisition workforce got hammered pretty hard by furloughs, sequesters, layoffs, and that that may have hurt the acquisition workforce expertise pretty significantly. If we're talking about really cutting-edge, you know, technology to help us with this third offset strategy, and some of it we're going to be acquiring, that's going to put a lot on the shoulders of the acquisition workforce to make wise decisions. Do we have—you know, DOD-wide, do we have the workforce we need to make the sophisticated acquisition decisions as we purchase these technologies?

Mr. WELBY. Senator, across the—enterprise, working for Under Secretary Kendall, we review, kind of, our workforce metrics continuously. We have a senior steering group that meets monthly, and we review it at the senior level quarterly, to ensure that we have—that we are—understand what's happening to the health of that workforce—hiring, retention, departures, the overall shape of the workforce. But, increasingly, the thing that concerns me is not numbers, but talent. Specific talent in areas like cybersecurity in areas like robotics——

Senator KAINE. Where competition is pretty tough——

Mr. WELBY. Where——

Senator KING.—so other opportunities are out there.

Mr. WELBY. I note that last week Google announced—and I believe the number was 20-percent raise across the board for everybody at Google who had "cyber" in their title. Not that they were being recruited, but just as a preemptive retention bonus. You know, our folks haven't seen, kind of, a 20-percent number, you know, ever, right? I don't think folks fully appreciate that, in some of the areas that were focused on—artificial intelligence, the cutting-edge computer-science work in cyber, in synthetic biology, in a number of other areas—we are getting great people because they love our mission, they love our capability. But, really, they're often giving up, kind of, integer multiples on compensation. Certainly over the course of their career, it becomes harder and harder, as folks try to get families, to think through how they can make that work.

I'm very appreciative for the great people who are working for us every day, but I worry about our ability to compete for talent in the future. It suggests we may have to think about other models for how we can recruit, retain, or engage those folks. If the government can't have them internal to our organization, how do we engage them outside? How do we ensure that we've got the right set of knowledge on our side of the table on the acquisition process? How do we have the right set of folks in our lab, thinking about the future for us? I think we're going to be in competition, not only for national security, but in the competition for talent, as our—as the commercial opportunities grow, as our Nation's vibrant innovation sector on the commercial side competes with the Department of Defense for talent. We're now mining the same spaces, and we're going to have to be creative as we go forward.

Senator KAINE. Let me ask a question. It kind of goes in a different direction on the third offset strategy. It's really doctrinal or conceptual. Earlier defense strategies—it's been easier for me to conceptualize how we integrate our allies into our strategies, you know, dealing with the Truman doctrine of the Cold War or even some of what we're doing right now, vis-a-vis engagements in Iraq and Syria. As we think about a third offset strategy that's heavily focused on novel technologies that are unique, swarm capacities, et cetera, how do we conceive of alliances and sharing of information? Or is the sharing of information, by definition, going to jeopardize your edge in a way that we can't do it? I mean, and that's a pretty broad question, but I've been wondering how we think about alliances and partners in connection with a third offset strategy.

Mr. WELBY. Just very quickly, for the sake of time. Allies and partners are going to be enormously important in almost everything we do. As we think about how we go to war, we always go with partners. We do not see that changing in the future. Much of what we're doing is thinking about how we have the right kind of discussions so that they can contribute and help shape that future. Today we're also looking at our allies and partners as partners, no kidding, in terms of the technology development itself, and how we start to begin to engage early on in capturing their benefit, as well.

I want to give Will a second to this—on this.

Dr. ROPER. I'll be very brief. It's very important, in the near-term response in the offset, to realize that we have two advantages that go back to more of the human side of the equation. One, we've been a preferred partner in the world. A lot of our allies and partners use the same equipment that we currently train with. We train with them on a routine yearly basis. It's a huge part of our readiness posture. As we start reimagining how we use our systems, there's a great potential to bring in allies and partners, and have that cross-pollinate so that adversaries aren't just facing a U.S.—a, you know, U.S. adversary, but they're facing a whole coalition approach.

Two is what you mentioned before. There's going to be commercial technology that's going to be cut into the mix alongside traditional military technology. Because it's commercially-based, it would be much more readily available to work on with allies and partners if we don't let exquisite requirements start pushing up what we try to get out of it, from a military capability. Cost is

going to be a very important metric in the offset. It's not just red cost, it's going to be blue cost, as well. What are we spending, what are they spending? Then what do we think the refresh rate of that technology will be? If we're wise, we will try to find capabilities in the commercial world where we're getting good bang for the buck, and keep an eye, Is it something we can share with allies and partners? If we can, then our coalitions that we build up play for us and not against us.

Senator TILLIS. Thank you, Madam Chair.

Dr. Prabhakar, I just—I was going to comment, if Senator Manchin had been here. I think probably the biggest distinction that you're dealing with between, say, the service academies and some of the other institutions is the nature of their research and investments that are being made by the Federal Government in the private sector. They create a different group of people that I assume you're collaborating with. I think I understand why there would be, necessarily, a different focus and different relationship with the service academies.

Dr. PRABHAKAR. Just a comment on that. If you look at all academic institutions broadly, of course there are many that focus on teaching and some that focus on research. Our natural partners for the research funding that we—especially the basic research work that we're doing, tend to be those research universities rather than——

Senator TILLIS. Yeah.

Dr. PRABHAKAR.—those focused on——

Senator TILLIS. Yeah.

Dr. PRABHAKAR.—education, which is more where the academies have been. That doesn't preclude—there are, in fact, some very good things that we've done there. I just didn't want to leave the impression that that was a major focus——

Senator TILLIS. Yeah.

Dr. PRABHAKAR.—for us.

Senator TILLIS. Yeah. I under—so, I just—and I think—I understood it; I just wanted to make that point.

Dr. Roper, and really for anyone on the panel, the—and it—when the Chair talked about "We're not really fighting tank-to-tank anymore," that's completely true. You know, our Air Force, our air capabilities will need to continue to evolve. I think we can build and iterate on our offensive and defensive capabilities. Probably the same is true for the Navy. But, for the people on the ground, like the folks I have at Fort Bragg and Camp Lejeune, they're being deployed in very different ways. I think Dr. Welby talked a little bit about the way that we will equip them, the way that they and the equipment and materials they're using could be semi-autonomous, tethered or loosely tethered, or untethered. I kind of understand how that would operate. But, at the end of the day, it's because we're going to have a dispersed group of smaller units on the field. The question then becomes, the—some of—many of your innovations are likely not to be these big, shiny ships and new missile systems that are going to be deployed on the battlefield, but they're going to be things that are very much connected to the humans and in the environments that we find ourselves fighting now. Could you talk a little bit about that, and also talk about the research that

you're doing that has less to do with offensive and defensive capabilities, but just pure-play force protection for the operators on the field?

Dr. ROPER. Sure. Thanks, Senator Tillis.

It's—there's going to be some, I think, amazing things that we'll be able to do with ground forces, given the commercial technology revolution that's going around us. Interpersonalwise, we're all carrying around fairly sophisticated high-processing, low-weight electronics that are massively networked and are completely enabled by cloud-based services. The military analog of this is obvious. If we can smartly find a way to transition this over and be able to do secure processing, and not have cyber vulnerabilities be a bigger headache than they are, the enabling capability from the technology themselves. We are working very closely this year with the Army and with SOCOM, some of the folks in your neck of the woods at Fort Bragg, on trying to find the balance between using commercial technology on the battlefront. I think there's a lot of promise there. One example that I'd like to highlight is work that we're doing with the Marine Corps on big data and analytics. You can imagine that all of these distributed systems that are going to be spread out over the battlefield are going to be producing data. That data is going to be pooled in a disaggregated way, but eventually pooled centrally. Understanding it, being able to give commanders that leading edge of decision authority is going to be important.

The Marine Corps right now is doing experiments with us currently, today, in the Philippines at the Balikatan Exercise, pulling in lots of information that supports that exercise, and synthesizing it using commercially-based big-data tools, something very new for us, and it's new for them. But, taking advantage, as Secretary Welby mentioned, of experimentation and prototyping, especially when the core of the systems we're using are commercially based, is going to be a very prudent way for us to get out and get the human side of the technology alongside, you know, the technology side. I see a lot of promise, but we're going to have to move into more of a rapid test-it, modify-it, retest-it in order to stay on top.

Mr. WELBY. Quickly. We often focus on those flashy pieces. We talk about tanks and missiles and aircraft. But, just last week, the Secretary announced the new Manufacturing Innovation Institute for Revolutionary Fibers and Textiles, a major initiative that's—crosses five State initiatives, that incorporates work going on around the country, thinking about fibers in a fundamentally different way. As an Active component in fabrics that might have woven-in electronics, might be able to serve, not just as protective gear, but as part of an ensemble—an active part of an ensemble to support warfighters, a kit, and with enormous applications to first responders and to medicare care and to an enormous number—another set of capabilities. We're not just thinking about how, you know, robots and new weapons kind of enable this future, but also thinking about how we make the individual warfighter more effective. I think there's a lot happening in that space, be it augmented reality kind of capabilities, be it soldier-borne compute, be it novel textiles and rethinking what a uniform means, thinking about how folks can be more effective, distributed for survivability,

and then massing for effect, even if they don't actually come together, but to be able to mass their effects. These are real opportunities to rethink the future of land combat. We're encouraging the Army and Marine Corps to help us think through that future in new ways.

Senator TILLIS. Thank you.

Dr. PRABHAKAR. May I just tag onto these excellent comments?

The nature of ground conflict, of course, continues to change. If you look at what's happening today and into the future, that environment is one in which we see—if you watch the Russians, if you watch what's happening on the ground with ISIL, you see this mix of kinetic effects, but, of course, also cyber effects. You see the use of the information domain. That used to mean dropping pamphlets or saying things on the radio. Of course, now it's social media. You see a different kind of use of the electromagnetic spectrum and jamming that we've not seen before. The integrated ability to bring all of that to bear is what our ground troops now will need to be able to deal with. A lot of our work is really thinking about how—for example, how do you enable a squad to not only survive in that environment, but actually exercise greater influence and have a larger footprint than it does today by leaping ahead of the kinds of things that are coming at us?

Dr. ROPER. One last point, Senator. That goes back to where we've—what we've touched on several times. The military that will be able to push the most amount of trust to the edge, assuming the enabling technology is there, is likely to win. It's an area where we have a significant advantage.

Senator TILLIS. Thank you.

Senator FISCHER. Thank you, Senator Tillis.

Senator Kaine, did you have other questions?

Senator KAINE. Just one.

Can you explain that last point you just made?

Dr. ROPER. It's a important point. I think we envision——

Senator KAINE. Repeat it. It—about the edge. Repeat that point.

Dr. ROPER. As we push, you know, where—there's always a desire, where you can, to do things in a centralized fashion. I want to have all the data flowing to the brain in the center, and then the commands will push out to the edge. As we discussed today, we're living in a complicated world. We're going to face cyber, we're going to face spectrum denial, we're going to face information operations, as Dr. Prabhakar mentioned. All of that is going to contest various nodes in that network. Data is not going to flow the way we want it to. The military that is able to have the most trust to interpret commanders' intent and the technology to allow them to back it up at the edge is going to have a significant advantage in the rapidity of their response. If we can move and enable that, we have an advantage over militaries who can't.

Well, when I go around and talk about with our operators, which is my great privilege to do so, and I contrast that with what I see in the rest of the world, I think we have an advantage in the level of trust in our chain of command. If we put the technology in the hands of soldiers that have our trust, then we're already a step ahead of the game. A lot of the technologies that you've heard dis-

cussed today are about trying to flow that enabling capability out to the edge of conflict, to the edge of the battlefront.

Senator KAINE. Great. Thank you very much.

Thanks, Madam Chair.

Senator COTTON. Sorry. I was coming over from an Intelligence Committee meeting. But, I know it's been an interesting hearing, just based on the written testimony that was submitted.

Secretary Welby, I want to talk about DCGS–A [Distributed Common Ground System-Army]. In your testimony, one of the areas you highlight are technologies and concepts that enable faster and better decisionmaking and coordinated operations at range and across the battlespace. Do you think the Department or the services should continue to develop major automated information systems?

Mr. WELBY. Senator, I believe that major automated information systems, there are places where the Department needs to be developing military-unique capabilities that don't exist anywhere else. I think where the Department is leveraging capabilities that are available from the commercial sector, we should not be in the business, and should be leveraging commercial innovation to the greatest extent possible. We see this in areas such as electronic health records, where we've shifted our focus to leverage commercial to the greatest degree. We see it in some of our log systems, where we had those kind of capabilities. I think we're seeing it increasingly in intelligence and data-fusion systems, where we can leverage commercial to a greater degree.

Senator COTTON. DCGS–A has been developed since the late 1990s, and it's been beset by cost overruns and schedule delays. Do you think this is one of those areas where we should perhaps move to commercial or private-sector solutions?

Mr. WELBY. Senator, I'm not fully fluent in the Army's current approach to that. I know they are reconsidering their strategy, in terms of that program.

Senator COTTON. Dr. Roper, do you have a opinion on this matter?

Dr. ROPER. On the DCGS–A, as a whole, no, Senator. I will say that, for the information tools that we're developing to leverage big data and analytics, we're relying heavily upon commercial tools, as well as those developed by our government DOD laboratories, as well as those developed by DARPA. I think developing architectures that enable as much of a rapid refresh of commercially-based tools would be wise, given the pace of development in the world.

Senator COTTON. An 80 or 85-percent solution would be acceptable today?

Dr. ROPER. It is for our operators, sir.

Senator COTTON. I think it was Patton, maybe MacArthur, who said, in a—something that was quoted in Infantry Field Manual 7–8, that a good plan today is better than a perfect plan tomorrow.

Dr. ROPER. To your point, Senator, the marines who are using our tools right now—and I'm getting feedback from them each day—we've never had this ability to coordinate on the information front, so they're learning, they're writing the training manual as we go. If we strive for exquisite solutions ahead of the operators' ability to use them to their fullest intent, we may have 100-percent

solution that's actually clocking at 80 percent on the battlefield. We have to balance the technology leap as well as the operator leap.

Senator COTTON. Do you think it make—would make sense to develop a program that had 120 different apps?

Dr. ROPER. It's appealing, given how enabling that is for us in our personal lives. That's very similar to how the tool I referenced works. It's called a—an Information Common Operation Picture, or ICOP, and it does work based on an app-based approach, where no one single piece of software developed, in most cases, by small businesses, provides operators precisely what they want. On the government side, we developed the integrating architecture and a display so that you can change out things behind the hood, but it looks the same way to operators on their screen. Now, that's for one particular application for looking at large amounts of publicly available information and making sense of it. How well those extrapolate to bigger architectures, including warfighting architectures, is a question I'm not able to comment on well.

Senator COTTON. Would it surprise you that the project manager found that, of the 120 apps, commanders and soldiers used, on average, 5 of them?

Dr. ROPER. I think it would, Senator.

Senator COTTON. Why is that?

Dr. ROPER. Well, just seeing how many apps I use in my own life, we tend to find—if it's useful, we tend to apply them personally. The reason for that is not one that I can comment on, but it does surprise me.

Senator COTTON. I mean, I'm sure, if we put a video game and an ESPN app on there, that soldiers would find a way to use those. But, if it's just the mission in front of them, I have to say I'm not terribly surprised that they're going for the simple route, since that's usually the best way to success in the Army.

I'm reminded of a story I heard once about Booker T. Washington when he was building his university. It may be apocryphal, but it's one of those stories that's too good to check, because it has an important lesson. That he built the buildings, everything was ready to go, students were ready to report, and someone pointed out to him they didn't have sidewalks. They said, "Are you going to build the sidewalks?" He said, "One day I might." About 6 weeks in, he took the engineers and the designers out and pointed out where all the grass was dead, and said, "Build the sidewalks there" rather than trying to force the students and the faculty to walk on sidewalks where he thought they should be designed and placed. I think that that probably could carry a good lesson for when we're designing this kind of system.

Thank you all for your testimony. Thank you for your answers to these questions. They're an important matter, and I'm sure the committee is going to be taking it up.

Senator FISCHER. Thank you, Senator Cotton.

I'd like to once again thank the panel. This was a fascinating discussion. I thank you for your work. It's important work. As I said earlier, we've always given you good support with this committee because of the support that you give our warfighters.

Thank you.

We are adjourned.

[Whereupon, at 4:02 p.m., the hearing was adjourned.]

[Questions for the record with answers supplied follow:]

QUESTIONS SUBMITTED BY SENATOR JOE MANCHIN

DARPA RESEARCH FUNDING AT FEDERAL DEGREE GRANTING INSTITUTIONS (FDGI)

1. Senator MANCHIN. Your agency funds research at universities throughout the US. What percentage of DARPA's fiscal year 2015 total research budget went to academic institutions?

Dr. PRABHAKAR. The total DARPA fiscal year 2015 funding sent to academic institutions was 13.4 percent.

2. Senator MANCHIN. The FDGIs include the service academies, so what portion of DARPA's fiscal year 2015 academic institution research funding went to the service academies?

Dr. PRABHAKAR. The total DARPA fiscal year 2015 funding sent to the Service academies was $2.0 million.

3. Senator MANCHIN. What portion of DARPA's fiscal year 2015 academic institution research funding went to other FDGIs (e.g., Naval Postgraduate School, Air Force Institute of Technology, etc.)?

Dr. PRABHAKAR. In fiscal year 2015, total DARPA funding sent to the Naval Postgraduate School was $1.6 million and to the Air Force Institute of Technology was $50.0 thousand.

4. Senator MANCHIN. I understand that research typically conducted at service academies and other FDGIs may not fully align with DARPA's preference for pivotal research investments in breakthrough technologies for national security. However, technology transition is critical for DARPA research success. The FDGIs have robust networks with their respective services for enabling technology transition and integrating faculty, cadets, and midshipmen into user evaluations. Do you assess that DARPA can feasibly pair its research performers with an FDGI to help enable technology transition?

Dr. PRABHAKAR. DARPA's unique role in DOD is to drive early investments to achieve breakthrough technologies for national security. As a result, the majority of DARPA programs do not transition straight into Service programs of record but are handed off to Service and industry partners for further research and development and prototyping.

In some cases, we do work with the Services and other FDGIs to demonstrate the operational utility of emerging technologies, and we have found that working directly with the eventual end-user communities is most effective. FDGI faculty and students are generally not current and future end-users. Working through the FDGIs for end-user evaluations would add another layer of complexity and effort between DARPA and our warfighting customers.

The Service Academies and FDGIs have typically not been key contributors to DARPA technology transition. There are a number of other Service entities and numerous other avenues that have proven to be far more effective in transitioning DARPA technology into warfighter capabilities. For example, the Service Academies have proven to be valuable on the early end of technology efforts to help shape emerging programs and provide a source of fresh ideas and perspectives on innovation. The DARPA technical offices have sponsored a variety of interactions and ongoing activities with the faculty and students of the Service Academies as well as the military post-graduate educational institutions, such as Naval PG School and AFIT to include them in user evaluations, solicit feedback and percolate new ideas.

5. Senator MANCHIN. Mid-career servicemembers selected for service academy instructor duty often enroll in civilian graduate schools that receive DARPA research funding. Do you assess that your agency could incentivize these schools to integrate servicemember graduate students into their DARPA research as a way to help enable technology transition?

Dr. PRABHAKAR. The services are responsible for determining research priorities for service academy instructors while studying in civilian graduate schools. They may consider several criteria including the technical needs of their future teaching duties as well as alignment with service priorities and funded research. In turn, DARPA does not attempt to influence the service-sponsored students' research topics or incentivize civilian graduate schools to integrate these students in our re-

search. We have found the approach that aligns best with our mission is to fund institutions competitively and without incentives, based on the their ability to meet the technical objectives of the proposed research using the best possible cadre of graduate students and faculty suited to the task. We also aggressively pursue technology transition working directly with the services to coordinate operationally focused evaluations by end user communities. In our best judgment, any effort to identify and incentivize individuals and institutions during our technical source selection could have adverse effects on choosing the best performers and would have very little impact on eventual transition.

DARPA does have several on-going programs to help connect mid-career officers with DARPA programs. These are designed to enhance their professional education and understanding of DARPA and the R&D enterprise at-large, as well as assist with technology transition. The DARPA Service Chief Fellows (SCF) Program provides for10–12 mid-career officers quarterly to attend a DARPA sponsored and funded 90-day fellowship at DARPA. While assigned to DARPA the SCF officers are exposed to the breadth of DARPA technology, experience some of its performer base first hand and help to provide insights to shape on-going programs and assist in transition. The insights and experience of the SCFs is of significant value to DARPA PMs on the potential military utility of various technological pursuits. The agency also has an established USAF Fellowship where it sponsors two mid-career officers for a longer term 10–12 month Fellowship to allow more prolonged exposure to DARPA and the R&D process as well as allow a more in depth interaction and integration for the Fellows with the DARPA Staff. DARPA is in the process of finalizing a similar long term Fellowship program with the U.S. Army.

QUESTIONS SUBMITTED BY SENATOR KIRSTEN GILLIBRAND

TECHNOLOGY TRANSFER AUTHORITIES

6. Senator GILLIBRAND. In several of the last Defense Authorizations, Congress has given the Department extended technology transfer authorities, including enhanced tech transfer capabilities to DOD Labs and expanding the partnerships that labs can develop for tech transfer. Can you tell us whether these authorities are being used? If so, how? If not, why not?

Secretary WELBY. The various technology transfer authorities given to the Department of Defense by Congress are being used. Examples of their utilization are included below.

Section 213 of the National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2016, Public Law 114–92, expands the scope of Educational Partnership Agreements (EPAs) to support technology transfer and transition. EPAs provide Defense laboratories the means to assist universities in extending their research capabilities in areas relevant to Defense needs and provide an opportunity for students to work on degrees in programs of interest to the Defense laboratory enterprise. Benefits to the Department are two-fold. One, the university develops scientific and engineering expertise applicable to future Defense needs. Secondly, students working on Defense-sponsored research receive early exposure to Defense labs thereby expanding the possible talent pool for future recruitment. One promising mechanism in which the Defense Department currently utilizes EPAs as a tool is the Open Campus Initiative. The Army Research Laboratory's (ARL) Open Campus business model envisions the creation of a dynamic, cooperative science and technology ecosystem that links government assets with the global research community. Open Campus partners work side-by-side with ARL research scientists and engineers, share ARL's specialized research facilities, bring ARL researchers to their institutions to communicate a perspective on research conducted in federal laboratories, and become part of the broader DOD network. ARL currently has an Open Campus presence at the Adelphi Laboratory Center, Aberdeen Proving Grounds, and the University of Southern California's (USC) Institute for Creative Technologies. The USC facility officially opened on April 13, 2016.

Section 252 of the NDAA for fiscal year 2013, Public Law 112–239, allows the Department to utilize the DOD R&E network to support regional advanced technology clusters to encourage the development of innovative advanced technologies and the commercialization of the same. As a result of this authority, the DOD established an on-going initiative with Arizona State and three DOD laboratories—the Air Force Research Laboratory Information Directorate in Rome, NY; the Space and Naval Warfare Systems Command in San Diego, CA; and the Army Natick Soldier Systems Center in Natick, MA. This pilot program pairs technology transfer professionals from Arizona State University and DOD Laboratories, and introduces ven-

ture capitalist and business accelerators to DOD technologies with commercial or private sector applicability. Local businesses, university students, and mentors from larger businesses (such as Honeywell, General Dynamics, and Boeing) collaborate in introducing viable DOD technologies to the commercial sector.

7. Senator GILLIBRAND. What are the barriers to technology transfer from DOD Labs, DARPA as well as from defense contractors and what can we do to help remove these barriers?

Secretary WELBY, Dr. PRABHAKAR, and Dr. ROPER. Much has been written in Academia, DOD and by the GAO regarding the traditional challenges and barriers to successful technology transition, including the specific challenges associated with DARPA's unique role in DOD to provide early investments to achieve breakthrough technologies for national security. As a result of DARPA's focus on early-stage research, the majority of DARPA programs do not transition straight into Service programs of record but are handed off to Service and industry partners for further development. However, given the unique nature of the advanced research conducted by DARPA, there are a variety of alternative ways in which DARPA technology transitions into future warfighting capabilities.

DARPA has a number of processes and resources available to Program Managers (PMs) to help navigate transition barriers. That starts with engagement with the Services and combatant commanders early in a program to help understand operational needs, elicit potential handoff partners, and build advocacy among operational users and resource sponsors. In recent years, DARPA has increased the resources available to support engagement and transition. IT established the Adaptive Execution Office (AEO) as a mission support element solely focused to help PMs by facilitating technical demonstrations, supporting incremental advances in technical maturation where appropriate and enhancing the handoff of DARPA technology to operational users and the Services. AEO works very closely with DARPA's four Active Duty operational liaisons to help PMs navigate the various barriers to transition and maintain connection with the Services and the COCOMs throughout the lifecycle of DARPA programs.