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HEARING

ON

NATIONAL DEFENSE AUTHORIZATION ACT FOR FISCAL YEAR 2017

AND

OVERSIGHT OF PREVIOUSLY AUTHORIZED PROGRAMS

BEFORE THE

COMMITTEE ON ARMED SERVICES
HOUSE OF REPRESENTATIVES
ONE HUNDRED FOURTEENTH CONGRESS

SECOND SESSION

SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES HEARING

ON

DEPARTMENT OF DEFENSE FISCAL YEAR 2017 SCIENCE AND TECHNOLOGY PROGRAMS: DEFENSE INNOVATION TO CREATE THE FUTURE MILITARY FORCE

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DEPARTMENT OF DEFENSE FISCAL YEAR 2017 SCIENCE AND TECHNOLOGY PROGRAMS: DEFENSE INNOVATION TO CREATE THE FUTURE MILITARY FORCE

HOUSE OF REPRESENTATIVES,
COMMITTEE ON ARMED SERVICES,
SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES,
Washington, DC, Wednesday, February 24, 2016.

The subcommittee met, pursuant to call, at 2:09 p.m., in room 2212, Rayburn House Office Building, Hon. Joe Wilson (chairman of the subcommittee) presiding.

OPENING STATEMENT OF HON. JOE WILSON, A REPRESENTATIVE FROM SOUTH CAROLINA, CHAIRMAN, SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES

Mr. WILSON. Ladies and gentleman, I would like to call this hearing of the Emerging Threats and Capabilities Subcommittee of the House Armed Services Committee to order. I am pleased to welcome everyone here today for this hearing on fiscal year 2017 budget requests for science and technology [S&T] programs within the Department of Defense. In a recent speech, Secretary of Defense Ash Carter spoke about the return of great power competition and the need to deter our most advanced competitors. We can only deter these competitors and adversaries when the Department of Defense [DOD] harnesses innovation and creates new capabilities for the military that will maintain and expand our technical superiority, now and into the future to achieve peace through strength.

The budget request is a good step in tackling the modernization challenges of the Department. Activities like the third offset strategy and the long-range research and development plan are important to charting a course that takes a strategic view of the security environment. However, I remain concerned that it is too little too late. As I see it, starting major initiatives at the end of an administration makes it difficult to ensure that these programs will survive the new budgetary and policy priorities that will naturally arise with a new President. I hope I am wrong, since I support many of the things being proposed in this budget request, but only time will tell.

I would like to welcome our distinguished panel of witnesses, and appreciate their perspectives on all of these issues. This panel includes Mr. Stephen Welby, Assistant Secretary of Defense for Research and Engineering; Ms. Mary Miller, Deputy Assistant Secretary of the Army for Research and Technology; Rear Admiral Matt Winter, U.S. Navy, Chief of Naval Research; Dr. David Walker, Deputy Assistant Secretary of the Air Force for Science, Tech-

nology, and Engineering; and Dr. Arati Prabhakar, the Director of Defense Advanced Research Projects Agency [DARPA].

I would like now to turn to my friend and ranking member, Mr. Jim Langevin, of Rhode Island for any comments he would like to make.

[The prepared statement of Mr. Wilson can be found in the Appendix on page 31.]

STATEMENT OF HON. JAMES R. LANGEVIN, A REPRESENTATIVE FROM RHODE ISLAND, RANKING MEMBER, SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES

Mr. LANGEVIN. Well, thank you, Mr. Chairman. And I want to thank you too—thanks to our distinguished witnesses for appearing before the subcommittee to address the Department of Defense science and technology policy and programs hearing for fiscal year 2017. Our S&T investments have been instrumental in delivering the capabilities necessary to address the threats that we have faced for more than a decade and a half from our enemies, like Al Qaeda and other terrorist organizations that seek to do us harm. Investments in S&T have also resulted in the very best protection for our troops from improvised explosive devices and other combat casualties. As long as our forces are still facing these adversaries, we must continue to invest in tools that could rapidly deliver the edge required for today's combat, while working to decrease technological surprise and maintain our edge against those threats on the horizon and beyond. Maintaining our technological edge is a priority for the House Armed Services Committee, and especially for this subcommittee.

As state actors continue to develop capabilities and leverage the latest technology, and non-state actors like ISIL [Islamic State of Iraq and the Levant] present new challenges to our information operations, it is imperative that the Department of Defense capitalize on the most cutting-edge technology and spur innovation for required capabilities. Doing so, however, requires more than just money. It requires the DOD to build lasting dynamic relationships with industry and academia while utilizing its in-house capability to the maximum extent possible.

The Department must also foster new relationships with nontraditional DOD partners. In the last 2 years, the Department has initiated two programs, DIUx [Defense Innovation Unit Experimental] and In-Q-Tel, intended to strengthen its collaboration with tech firms, entrepreneurs, and start-ups.

In-Q-Tel has a proven track record with the intelligence community and has the potential to bring the same success to DOD. DIUx seems to be a mechanism for relationship building, but it remains unclear to me exactly what their role is, and how they are interfacing with transition offices, program managers, and others in the existing S&T and acquisition communities.

While I support efforts to access and harness new technologies, I want to ensure the Department is fully leveraging its existing toolbox, like small business innovation programs, rapid innovation funds, transition offices, and prototyping accounts in place. I would appreciate hearing the witnesses' views and understanding of these mechanisms.

Innovation also requires the Department to be able to recruit and retain a talented workforce. I believe the Department's workforce is a critical element in maintaining our technological edge, and I look forward to hearing from our witnesses about what they may need as it pertains to current hiring authority modifications, or new authorities to ensure that we are investing in the very best and brightest minds available.

Another essential element in maintaining our technological edge is the Department's in-house infrastructure. DOD labs are a national asset; yet, the 2017 budget remains void of investment in physical facilities. The subcommittee has attempted to address the lack of military construction funds for labs by providing limited authority to use RDT&E [research, development, test, and evaluation] funds. But today, I hope to hear about infrastructure investment requirements and continue a dialogue about how those requirements can be met.

With that, I just want to thank all of the witnesses for being here today. I appreciate the work that you are doing in very cutting-edge fields. You are all involved in investing in your time and energy in looking at those high-risk, but high-payoff, technologies that are going to keep our military highly effective and our warfighters very safe.

So with that, I want to thank you again for being here and giving your distinguished service to the Nation.

Thank you, Mr. Chairman, and I yield back.

Mr. WILSON. Thank you, Mr. Langevin. I would like to remind each witness that your written statements will be submitted for the record. We ask you that you summarize your comments to 5 minutes or less, and then after each one of you have made a presentation, each member of the subcommittee will have an opportunity at 5 minutes, and Kevin Gates is very strict on that 5 minutes, and you will notice that he cuts us off, so that we can all have an opportunity to participate. And again, we just appreciate your service so much.

Mr. Welby, we will begin with you and we look forward to your opening statement.

STATEMENT OF STEPHEN WELBY, ASSISTANT SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING, OFFICE OF THE UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY AND LOGISTICS

Mr. WELBY. Chairman Wilson, Ranking Member Langevin, members of the subcommittee, I am pleased to appear before you today and have the opportunity to provide testimony on the Department of Defense's fiscal year 2017 science and technology program, and to join my colleagues from across the services and DARPA to report on the current state of science and technology in the Department.

The DOD S&T program works to deliver a balanced portfolio of technology to the Department informed by awareness of global technology trends and critical threat capabilities. I believe we are at a pivotal moment in history. And the chairman mentioned this in his opening statement where the capacity that the Nation has relied upon to provide us with unmatched technological superiority on the battlefield is now being challenged. It is being challenged by

investments in military technology being made by increasingly capable and assertive foreign powers. I believe that today, and, in fact, every day when I visit our laboratories and organizations across the defense enterprise, I encounter young scientists and engineers pursuing technological innovations motivated to meet the challenge that we see emerging globally, launching new and emerging capabilities in a variety of disciplines, and applying those technologies to create improved military capabilities informed by operational experience and needs.

Our Department-wide focus on technological innovation seeks to identify and invest in those unique capabilities that can sustain and advance the Department's conventional military superiority into the 21st century. As Secretary Carter mentioned in his remarks on the budget at the Economic Club of Washington on the 2nd of February, we must take the long view and seize opportunities for the future in order to sustain our lead in full-spectrum warfighting.

Today, the Department employs over 39,000 scientists and engineers in 63 defense laboratories, warfare centers, and engineering centers across 22 States, sustaining our ability to support and field militarily critical technology that often has no commercial equivalent. Our laboratories have produced very significant innovations in vital defense areas such as electronic warfare, propulsion, and weapons design. And maintaining this unique technical expertise within the Department is critical for ensuring the Department's ability to prepare for future threats.

Over the last year, the science and technology community has not only supported the immediate needs of our warfighters, but also has taken action that has had strategic impact in the areas such as helping to eliminate Syria's chemical weapons stockpile and helping to deploy diagnostic laboratories to curb the spread of Ebola in West Africa.

However, we cannot innovate and bolster our future technological superiority from within the Department alone. Our defense S&T enterprise touches the broadest range of emerging concepts through our deep engagement with academia, with industry, and our international partners, to help keep the DOD smart, knowledgeable, agile, and responsive in the face of new and emerging threats.

This includes, as was mentioned, an outreach to a vibrant and growing commercial innovation community that sometimes doesn't see the Department as a natural customer, and doesn't think initially to apply their technologies to the national security sphere. And we want to break down those barriers and engage that fast-moving sector.

In those areas, investments being made by the commercial technology sector are accelerating the development of technologies with critical relevance to future defense capabilities. Many of these small innovative commercial firms lack knowledge about defense systems, organizations, and problems that could benefit from their products and technology, and that is why we have made investments in activities like DIUx in Silicon Valley as a way to help match DOD customers with some of those potential sources of advanced capabilities that are rising from the commercial enterprises.

As the Department looks to its future, there are significant challenges that will require renewed emphasis on sustaining our U.S. technological superiority. The United States must seek to develop and maintain asymmetric advantages, those that take advantage of fundamental U.S. strengths in military and commercial technology innovation and apply them to outcompete our competitors.

We must accelerate our approaches to identifying promising technology differentiators, improve our process for mapping technology capabilities to operational advantage, and continue to focus on methods of moving capability much more rapidly from laboratory to field.

For the last 6 years, the Department has engaged in a major effort to improve our internal acquisition processes through the Better Buying Power initiatives. The latest iteration of Better Buying Power 3.0 focuses the acquisition system of the Department on achieving dominant capabilities through technological excellence and innovation. That emphasis reflects the criticality of research and engineering on our overall acquisition success and emphasizes the need to bring and support a strong and effective DOD laboratory enterprise.

I want to point out just very quickly three of the many Better Buying Power initiatives that are relevant to our S&T community. The first is the use of prototyping and experimentation to accelerate operational assessment and adoption of key technologies to advance current and future weapon systems. The second is the support for robust DOD STEM [science, technology, engineering, and mathematics] engagement to ensure that we have a future workforce and a pool of defense-relevant technical talent available to us to ensure our future capabilities.

And, finally, I want to point out that the Better Buying Power reinforces the cost consciousness of our S&T community using tools like "Should Cost," to ensure that we're getting the best return on investment for our taxpayer and warfighter.

Our strength is in our people. We must recruit, retain the best and brightest military and civilian scientists and engineers and harness their innovative spirits to give our military forces a warfighting edge. Ultimately, our goal each day must be to ensure that our soldiers, sailors, airmen, and marines all have the scientific knowledge, the right technology, the advanced systems and tools, the best care, and the decisive advantage and material edge to succeed when called upon. Our research and engineering enterprise really does need to measure its success in the security of our Nation and the success of our warfighters. And we are trying to drive that home in everything we do.

Let me thank you for your support for the Department's science and technology efforts as we work to discover, design, and deliver those technological capabilities that our warfighters will need to shape the future.

[The prepared statement of Mr. Welby can be found in the Appendix on page 32.]

Mr. WILSON. Thank you very much, Mr. Welby.

We now proceed to Ms. Miller.

STATEMENT OF MARY J. MILLER, DEPUTY ASSISTANT SECRETARY OF THE ARMY FOR RESEARCH AND TECHNOLOGY, OFFICE OF THE ASSISTANT SECRETARY OF THE ARMY FOR ACQUISITION, LOGISTICS AND TECHNOLOGY

Ms. MILLER. Chairman Wilson, Ranking Member Langevin, and distinguished members of the subcommittee, thank you for this opportunity to discuss the Army's science and technology program for fiscal year 2017. The United States faces a complex and growing array of security challenges across the globe. A new generation of threats and opportunities has emerged, and will continue to develop in unprecedented ways. Technology is evolving and proliferating at an exponential rate, and our enemies' access to this technology has closed the gap in our operational overmatch. We are in a race with our adversaries to harness and field the best military applications of innovation.

In the 1990s the Army made great strides to advance night vision technology into operational capability to own the night. Based on those early S&T investments and the great work of our industrial base, the U.S. has enjoyed overmatch in night operations for almost two decades. Today other countries have developed or acquired similar capabilities, eroding our significant advantage. This is just one example of the impact of the globalization of technology, and emphasizes our need to continue to innovate alternative technologies and operational methods to maintain overmatch.

The Army S&T enterprise cannot predict with certainty what challenges and threats the future holds, but it can organize itself to help prepare for the future, mitigating the possibility of technical surprise and ensuring that we remain dominant in any environment. Transparency, efficiency, and flexibility help us to invest our limited resources where they have the greatest payoff. This framework allows us to adjust our approach in response to changing circumstances. I am proud to represent the U.S. Army's nearly 12,000 scientists and engineers who are innovative change agents committed to solving difficult national security challenges and developing the capabilities needed by America's soldiers to overcome adversaries, both today and into the future.

In past years, I have detailed to the committee our enduring Army challenges and how they influence the Army S&T's technology portfolio investments. Today, I would like to take this opportunity to describe some newer strategic initiatives that cut across our portfolios, and are instrumental in helping us realize our objectives. To quote General Milley, the Chief of Staff of the Army, "We will do what it takes to build an agile, adaptive Army of the future. We need to listen and learn, first from the Army itself, from other services, from our interagency partners, but also from the private sector and even from our critics. Developing a lethal, professional, and technically competent force requires an openness to new ideas and new ways of doing things in an increasingly complex world. These strategic initiatives that I am discussing here are designed to help the Army do just that. Listen, learn, change, and adapt."

Technology war gaming is a reconnaissance effort undertaken by the S&T enterprise to foster greater innovation. It is focused on identifying concepts and conducting technology-based assessments about what technology will look like in the deep future, the 2030

to 2040 timeframe, and how this will affect both the Army and our adversaries. It includes crowd-sourced brainstorming, conducting virtual workshops with subject matter experts, and red teaming potential technology concepts to ensure technical feasibility.

At the heart of this initiative lies a commitment to solid analysis and a focus on bringing in fresh ideas from a wide community, including innovative thinkers who haven't traditionally been a part of the Army's S&T planning process. We use these war games as the basis for strategic conversations on potential leap-ahead capabilities for the future force and how best to align resources and organizations to pursue those opportunities.

Another key component of our S&T strategy is broadening and deepening our ability to identify, understand, and eliminate potential vulnerabilities in emerging technologies and future systems that could threaten their success upon deployment in Army operational settings against an evolving and responsive threat. Our S&T red-teaming investment provides in-depth, independent assessments of emerging technologies across laboratories, tabletop, and live-build environments. A number of years ago, the Army entrusted my office to initiate a pilot focused on technology transition. They established a budget activity for funding line with the intent to enable the Army to better transition across the often-cited "valley of death." This pilot began with a small amount of dollars, but with a large vision, a vision that hinged upon establishing collaborative partnerships with the acquisition and requirements communities, conducting co-led technology maturation efforts for pre-milestone A or B activities leading into programs of record, and building prototypes that could be used by operators in mission scenarios to allow candid feedback on new capabilities.

By understanding the technology trends of the future, assessing technology and system vulnerabilities, and conducting maturation and prototyping earlier in the acquisition life cycle, we can identify and address areas of risk before the government commits funding to programs of record. Ultimately, it is more cost effective to prove out innovative concepts and capabilities within the science and technology program than it is under a formal program acquisition.

Finally, I would also like to acknowledge the support provided by members of this committee and your staff. Congress is one of our most important partners, and your strong support of the S&T enterprise helps ensure that the U.S. Army remains a preeminent force in the world. The Army S&T mission is never complete. We will continue working to ensure that our soldiers are always equipped with the technology to win. We owe our soldiers no less. Thank you, and I would be pleased to answer any questions you may have.

[The prepared statement of Ms. Miller can be found in the Appendix on page 46.]

Mr. WILSON. Thank you very much, Ms. Miller.

And we now proceed to Admiral Winter.

STATEMENT OF RADM MATHIAS W. WINTER, USN, CHIEF OF NAVAL RESEARCH AND DIRECTOR, INNOVATION TECHNOLOGY REQUIREMENTS, AND TEST AND EVALUATION (N84)

Admiral WINTER. Good afternoon, Chairman Wilson, Ranking Member Langevin, and distinguished members of this subcommittee. Thank you for the opportunity to appear before you today to discuss our Department of the Navy [DON] science and technology investment strategy that ensures our sailors and marines will retain the technological advantage on the battlefield, which is absolutely essential. Today, I am representing an incredible team of more than 4,000 scientists and technical professionals in the naval S&T community. My testimony will provide a snapshot of our naval S&T investment strategy that is fully supported by the President's fiscal year 2017 budget request.

As you know, the DON has a rich history of pushing the boundaries of our science and technology to ensure our Navy and Marine Corps are equipped with the capabilities that they require to perform the full range of military operations assigned to our naval forces in every theater against every known threat. Our ability to maintain that decisive technological advantage starts right here at the Office of Naval Research [ONR]. With our 70th anniversary this coming August, the Office of Naval Research has been delivering that technological advantage to our naval forces for over seven decades, leveraging the intellectual capital of our scientists to discover the new knowledge that generates the breakthrough technologies that delivers the innovative solutions to win our Nation's battles, and as importantly, strive for a global peace.

The President's fiscal year 2017 budget request funds the required initiatives to support our Naval S&T Strategy, which is a key enabler in realizing our Navy's design for maintaining maritime superiority, and our Marine Corps' priority for modernization and technology outlined in Advance to Contact strategy, both of which were unveiled in January by our Chief of Naval Operations and our Commandant of the Marine Corps, respectively. Our logical and forward looking science and technology investment strategy leverages our S&T community triad—academia, industry, and government performers—to realistically deliver technological advantages.

Our investments continue to yield a very high rate of return in terms of intellectual capital growth through our extensive academic STEM outreach initiatives, fostering of new innovative small businesses through our Small Business Innovative Research initiatives, and providing of game-changing, next-generation capabilities for our sailors and marines through the partnerships with academia, industry, and our naval research and development establishment.

During my first full year here as the Chief of Naval Research, this team has accomplished this a lot. We have awarded over 4,000 academic grants to domestic and international universities, inspiring and retaining the Nation's best and brightest talent. Our basic research conducted at our premier Naval Research Laboratory has generated over 200 basic research projects, resulting in discoveries of new knowledge, phenomenologies, and technologies.

Last year, we filed over and were awarded over 380 technical patents for new discoveries. It was the 16th consecutive year that

the U.S. Navy ranked first amongst all U.S. Government agencies. And we successfully transitioned and demonstrated over 200 key technologies across that "valley of death" out of S&T to our warfighters and to programs of record. Leveraging these accomplishments, our ONR teams are executing ongoing research programs in a number of key priority areas that are yielding that high payoff and potential game-changing capabilities for our sailors and marines.

I would like to highlight a couple. Directed energy. Our directed energy efforts will enable our naval forces to truly fight at the speed of light. ONR-funded research delivered a solid state laser to the USS *Ponce* last year, successfully demonstrating destruction of surface and air targets. Our hypervelocity projectile program, the HVP, was successfully fired from a 5-inch Mark 45 gun with a ballistic range of 34 nautical miles. We have had over 40 HVP firings to date, and have been executed paving the way for accelerated transition and leading to significant capabilities enhancement for our future naval force.

Another critical warfighting enabler is access to assured information by keeping our Navy and Marine Corps cyber doors locked. Our naval tactical cloud research is providing the framework and big data analytics for our platform cyber defense solutions such as resilient hull, mechanical, and electrical security system. We call it RHIMES. RHIMES is a cyber protection system designed to make its shipboard mechanical and electrical control systems resilient to cyber attacks.

Autonomy. Autonomy in the undersea domain is extending our capabilities in new ways. We have demonstrated our hybrid fuel-cell-powered large displacement unmanned underwater vehicle. We call it LDUUV. And it completed its first tests at our Naval Surface Warfare Center, Carderock, and demonstrated the ability to launch a fuel-cell-powered unmanned aerial vehicle [UAV] from the underwater vehicle.

Finally, our warfighters will benefit from our incredible breakthroughs in synthetic biology and medical research. Advances in medical technology, for example, including 3–D printing of live tissue into arteries, veins, and capillaries, will ensure that those in the battle and those returning from battle will not only survive, but will thrive.

Throughout this coming year our focus will remain on rapidly delivering these innovative technological solutions. Examples of our initiatives coming in 2016: two new forward-looking innovative naval prototypes that will push game-changing technologies and capabilities to maintain our superiority in the undersea domain and our electromagnetic domain. Directed energy efforts will continue on the USS *Ponce.* We will leverage those lessons learned and we are moving forward with the technology maturation effort of a 150-kilowatt capability for future platforms.

While we continue to work on the ground-based capabilities with our United States Marine Corps, the GBAD [Ground-Based Air Defense] system, which will give a vehicle-based, high-energy laser capability to our 21st century marine. We also are demonstrating at-sea capability for our low-cost UAV swarming technologies. We will

be able to launch, form, control, and task 30 UAVs in an offensive swarm.

And finally, we will take the next step in undersea autonomy, and we will conduct a long endurance transit test of our LDUUV operating submerged from San Diego to San Francisco. Our ONR scientist contributions are marked and making a marked difference to our Navy and Marine Corps. Key to these accomplishments are our partnerships. Partnerships with industry and academia, partnerships with our sister services and DARPA, and through our six ONR global locations around the world in London, Prague, Tokyo, Singapore, Santiago, and San Paulo, working with our international S&T partners around the world. We will continue to expand and deepen these partnerships to execute our S&T mission.

Through innovative research, disruptive thinking, and high-velocity learning, always striving to make existing systems more effective and affordable while improving breakthrough technology transitions to acquisition programs and our sailors and marines. And in doing so, we remain aligned with our Navy and Marine Corps leadership. Our Chief of Naval Operation and Commandant of the Marine Corps' strategic guidance is underpinned by our forward-thinking S&T investments.

We cannot afford to do business as usual and wish away the technological advantages of emerging global actors that are challenging our warfighting supremacy. Our S&T strategy provides the framework to think and act differently for success. We must be committed, all of us committed, to pursuing the technology solutions for tomorrow today. It is essential to tie the technical to the tactical to the strategic. And we in the Navy and the Marine Corps are committed to ensuring the S&T resources that you and your congressional colleagues provide us gets the most bang for the buck by giving our sailors and marines the technological advantage on the battlefield to fight the fight and keep the peace.

One final note, I offer to each and every one of you an open invitation to visit one of our 50 warfare centers and system centers around the world—or excuse me, around the United States. And right here in Anacostia, our Naval Research Laboratory, where you can get a firsthand look at our world-class scientists, engineers, civilian employees that are the ones that are really making things happen. Gentlemen, I appreciate and thank you for your time this afternoon and your continued support of our S&T efforts. I look forward to answering your questions.

[The prepared statement of Admiral Winter can be found in the Appendix on page 66.]

Mr. WILSON. Admiral, thank you very much. And it is very encouraging to hear about the public/private partnerships you identified.

Dr. Walker.

STATEMENT OF DR. DAVID E. WALKER, DEPUTY ASSISTANT SECRETARY OF THE AIR FORCE FOR SCIENCE, TECHNOLOGY AND ENGINEERING, OFFICE OF THE ASSISTANT SECRETARY OF THE AIR FORCE FOR ACQUISITION

Dr. WALKER. Thank you. Chairman Wilson, Ranking Member Langevin, members of the subcommittee and staff, I am pleased

again to have the opportunity to provide testimony on the fiscal year 2017 Air Force Science and Technology Program, and our efforts to innovatively and affordably respond to warfighter needs today, while simultaneously creating the force of the future. I would like to thank Congress, and especially this subcommittee, for your continued support of the Air Force's S&T programs, our laboratories, the infrastructure, and most importantly, our valuable scientists and engineers. Over the past 3½ years that I have been the Air Force's science technology executive, I have seen the fruits of your labors and our ability to advance game-changing technologies, continue to develop our people, and strengthen the industrial base for the long-term security of our Nation.

As you have heard from my colleagues today, and from the Air Force senior leaders in the past, we are at a critical juncture in history. The relentless pace of change continues to increase the complexity and decrease the predictability in warfare. We believe our science and technology program capability development processes, our STEM workforce, our laboratory infrastructure, are all critical to achieving new levels of strategic agility to address this rapid rate of change. By strategic agility, I mean harnessing the attributes of flexibility, adaptability, and responsiveness in order to make us more effective in a rapidly changing world.

As highlighted in the Air Force strategy, strategic agility allows us to address evolving threat environments faster than our adversaries, which can help us counter uncertainty. Our efforts in this area, many of which are described in my written statement, support the Department's third offset strategy and are aligned with the long-range research and development planning program.

Further, the Air Force is leveraging Mr. Kendall's Better Buyer Power 3.0 initiatives to strengthen our ability to innovate, to achieve technical excellence, and to dominate—to field dominant military capabilities. Air Force senior leadership is committed to S&T investment and embracing new paradigms and capability development. Our fiscal year 2017 President's budget request for S&T is approximately $2.5 billion, which represents a 4.5 percent increase over our fiscal year 2016 budget.

We emphasize research in hypersonics and low-cost cruise missile technologies for contested environments in support of the long-range research and development planning program. We are working on advanced combat missiles and research and technologies that provide robust position, navigation, and timing capabilities; and, also, focusing on the Air Force's game-changing technologies which include hypersonics, autonomous systems, unmanned systems, directed energy, and nanotechnology.

As a whole, this research is designed to amplify the speed, range, and flexibility and precision of air power. Our fiscal year 2017 President's budget request also includes increase funding in budget activities 4 and 6 to support our development planning, prototyping, experimentation, and our model and simulation efforts. The reinvigoration of development planning in the Air Force at the enterprise level gets us back to our roots, and allows us to really formulate innovative strategy choices and the leveraged attributes of agility and our capability to development. The Air Force is using enterprise capability collaboration teams as an approach to facili-

tate the developmental planning of our highest priority mission areas. These teams are chartered by senior leadership to explore cross-domain concepts of operations, combined with the existing and emerging technologies to address future warfighting gaps.

The ultimate goal is to identify capabilities, concepts of operations, emerging technologies to inform acquisition decisions in the future. Experimentation is the engine to our reinvigorated development planning process. It enables the unfettered exploration of alternatives of future—future environments and brings together our operators, it brings together our technologists, the requirements generators, and the acquisition professionals, all collaborating together from the beginning to the end to develop a truly integrated approach to solving warfighting problems.

We are currently conducting four pilot experimentation campaigns addressing future concepts for close air support, operationalized and directed energy, reducing time to move from data to decisions, and defeating agile and intelligent targets. We are also focusing on prototyping as a valuable tool across all levels of technology maturation from initial concepts to operational prototypes. Our adaptive engine transition program is an excellent example of prototyping being used to reduce risks and bridging the gap between S&T and a program of record.

None of these efforts would be possible without our world-class scientists and engineers operating state-of-the-art laboratory facilities. We continue to leverage the authorities and lab demo, the SMART [Science, Mathematics and Research for Transformation] scholarships, and other funding sources to recruit, retain, and develop our Air Force STEM workforce. In addition, we are leveraging section 219 and MILCON [military construction] funding to build and maintain world-class laboratory facilities for them to operate in.

Chairman, and members of the subcommittee and staff, thank you again for the opportunity to testify today. I look forward to your questions.

[The prepared statement of Dr. Walker can be found in the Appendix on page 86.]

Mr. WILSON. Thank you very much, Dr. Walker.

We now proceed to Dr. Prabhakar.

STATEMENT OF DR. ARATI PRABHAKAR, DIRECTOR, DEFENSE ADVANCED RESEARCH PROJECTS AGENCY (DARPA)

Dr. PRABHAKAR. Thank you, Mr. Chairman, Mr. Langevin, members of the subcommittee. I will add my thanks for this opportunity to be here with my colleagues.

DARPA works closely with this entire defense science and technology community. And we also work with defense companies, with commercial companies, with universities and labs of all sorts. We are very much part of this wide ecosystem. Within that ecosystem, DARPA has one specific role, and that is, to make the pivotal early investments in the technologies that can have huge impact, offscale impact, on the future of national security.

Now, today when we do that work, we do it in the context of these shifts in the global security environment in a world that is filled with fast-moving technologies, very much the themes that we

have been talking about this afternoon. I wanted to give you one concrete example that brings all of that to life, and it is an example about aircraft self-protection. Today, when our aircraft go out on their missions, they are loaded up with a set of jamming profiles. So these are specific frequencies and wave forms that they can transmit in order to jam and disrupt an adversary radar to protect themselves.

Sometimes when they go out today, they encounter a new kind of frequency, or a different wave form, one that they are not programmed for, that is not in their library. And in a time of conflict, that would leave them exposed. So what do we do when we come across that situation today? Today what we do is we have to send a new aircraft out, a different aircraft out, to collect that signal. That signal is then sent to a lab where it is analyzed, where a new jamming profile is created, where the development—where the new software upgrade for the system is developed, and then eventually, months, sometimes years later, our aircraft finally get the protection that they need against this new kind of radar signal.

Now, in a time when our adversaries were changing their radar signals very rarely, that might have been okay. But, of course, that very slow-moving world is now gone. And in fact, it is actually just not that hard to modify a radar system today. If you think about it, the same technologies that brought—that have brought communications and the Internet to billions of people around the world, those are the same technologies that now people are using to modify radars to shift the frequencies and they use new wave forms. And we see that going on in many different regions around the world.

One of our programs at DARPA is taking a whole new approach to this problem, this is an effort that we refer to as cognitive electronic warfare. We are using artificial intelligence to learn in real time what the adversary's radar is doing, and then on the fly, create a new jamming profile. And that whole process of sensing, learning, and adapting is going on continuously. So what all of that means is that our aircraft in the future won't have to wait weeks—you know, months to years, but in real time, in the battlespace, they will be able to adapt and jam this new radar threat that they get.

I think that is just one example of how powerful it can be to first accelerate these areas of research and technology, and then apply them for our military capabilities. And across the DARPA portfolio, you will find many, many other examples of that kind of power of technology. They range from new systems that we are developing. We just put in the water our new surface vessel that will be able to navigate across the open ocean by itself without a single sailor onboard. If you look across our research portfolio, you will find that we are harnessing photons and algorithms, and even living cells to open possibilities that people really just couldn't even have dreamt about until today. And I am happy to talk about all of that, but I want to finish this afternoon by just touching on two pillars of your support that are so vital for us to be able to do this work.

The first, of course, is the budget. And your support here has been vital to a relative stability that we have benefited from at

DARPA over the last few years. So I will ask again for your full support of the fiscal year 2017 President's budget request level.

The second area is people. And, of course, nothing could be more important to that—than that. I want to really give a special thanks to the work that this committee has done over many years, first in creating a special 1101 hiring authority, and then over many years, supporting that. That is a big reason that DARPA is able to move fast and hire exceptional people. And really, you know, great people and that trust that you have in us, that is why DARPA is able to develop breakthrough technologies that allow us to take these huge strides forward in our national security capabilities. And with your continued support, that is exactly what we will continue to do. So thank you very much. And I look forward to answering questions along with my colleagues.

[The prepared statement of Dr. Prabhakar can be found in the Appendix on page 126.]

Mr. WILSON. And, Dr. Prabhakar, thank you very much. And I also want to thank you so much for the opportunity I had to visit your facilities, to visit your personnel. It really is reassuring, and I hope that other members of the subcommittee will take advantage of the open invitation you have 24 hours a day, 7 days a week, to come visit. And—but it really is inspiring, the personnel that you have assembled.

As we now begin the very strict 5 minutes, beginning with me. Mr. Welby, could you explain the third offset strategy? How are science and technology investments being aligned to support that strategy?

Mr. WELBY. Thank you, Mr. Chairman. As we have discussed in, I think, every statement here today, we find ourselves increasingly challenged by near-peer competitors who are investing in high-end capabilities, in ballistic missiles, in advanced cruise missile technology, in advanced electronic warfare and other capabilities that directly challenge U.S. systems. We recognize that as we look to the future, it is going to be increasingly difficult to compete with those capabilities in an investment-for-investment, dollar-for-dollar, system-for-system basis. We need to be thinking harder about how we shift the shape of competition, the playing field on which our soldiers, sailors, and marines will be fighting into areas where can ensure the United States has an enduring dominant technical capability.

The Deputy Secretary regularly talks about the first and second offset strategy, looking back to competition with the Soviet Union, and in the 1950s, how technical nuclear weapons were deployed to counter the numerical superiority of that threat and how, in the 1970s and 1980s, the Department developed precision weapons, ISR [intelligence, surveillance, and reconnaissance], low observability, novel use of space, network-centric capabilities, the toolkit that we have fought with since to remarkable success.

Today, we now see others around the world building capabilities directly designed to blunt those U.S. advantages. We now see others having those capabilities which were once purely the domain of the United States. And as that symmetry begins to develop between ourselves and potential competitors, we want to assure that we have asymmetric advantage that we can deploy in the future.

This whole discussion about offset strategies is about finding those technology offsets, how they map into operational capabilities, how we can invest in those capabilities that will begin to move the ball in a way that will shape a longstanding advantage for U.S. capabilities.

And we believe those capabilities will rise from the emerging technical innovations that were discussed here today in areas like thinking about new long-range systems and exploiting manned/unmanned machine teaming in new ways and leveraging autonomy to build things like cognitive warfare systems, electronic warfare systems, and thinking about spectral agility, and many of the things that we are working on in our laboratories, but moving them faster into tactical application and arranging those into strategic concepts that will allow our forces to shape future battlefields.

The topics that were mentioned earlier, things like the long-range research and development planning program, an activity that I led for the previous 18 months, provided a set of potential options for the future of the Department, new material systems that might offer significant advantage in the future, that report—while the report itself remains classified, is reflected in the support and decisions that were made in the shaping the 2017 budget submission, and informed by many—a number of other studies in areas and the ongoing war-gaming activities that are going on across the Department.

And, so, the third offset strategy is not a thing, if you will. It is an ambition to think differently about how a department will fight in the future, how the services will align technology, organization, and capabilities to provide that enduring advantage. But it is underpinned in a very significant way by our critical technology investments we are making here across the services.

Mr. WILSON. Well, as a very grateful dad of four sons serving in the military, I appreciate you thinking ahead on how to protect our service members and protect the American people.

And, Dr. Prabhakar, could you describe some of the efforts DARPA has initiated to combat the ability of groups like Daesh to spread violent extremist propaganda and radicalize users online.

Dr. PRABHAKAR. Mr. Chairman, you have touched on something that is increasingly becoming integral to any kind of conflict around the world. Obviously, I think, we are all aware of the use of social media by ISIS [Islamic State of Iraq and Syria], ISIL. It is also very integral to hybrid warfare that we see the Russians engaging in. So I think it is a vital important area today.

DARPA has had programs over the last several years that bring data analytics and tools to end users so that they can start to wrestle with this vast array of bits that are flying at them, whether it is military information or open online information. And building on those today, we are developing some tools that we hope will be very helpful in these kinds of future information conflicts. One specific area in the last year where we have had some good progress, last couple of years, has been focusing on the impact on what—we have been working with law enforcement who have been worried about human trafficking. And they have been struggling to really see—you know, if you think about where people advertise for the sex trade, for example, a lot of that is open advertising. But right now

our law enforcement partners, we found, really are sort of searching that space single threaded, one Google search at a time, if you like, a very arduous way to figure out the patterns and the connectivity of the kinds of ads that are being served up.

So what we have developed, in that case, was a set of tools that allow for very deep domain-specific, deep Web search, not just the surface Web that is indexed by Google or Bing, but really an ability to go deep into the open Web and find all the linkages among ads, for example, for human trafficking, that are related to human trafficking.

What we find is that it dramatically enhances our law enforcement partners' ability to find those linkages. And that tool is now being used, for example, by the district attorney's office in New York, and has led to a number of indictments, and even at least one conviction.

So I think that gives you a little bit of a sense of the power of the kinds of tools. When you apply these big data approaches to these areas like law enforcement, you can see, I think, how that would extend into the information warfare domain that sadly, I think, is going to become integral to conflicts going forward.

Mr. WILSON. Well, thank you very much. And thank you for citing about human trafficking. I am very grateful. My home State of South Carolina, by State legislation and prosecution, has been one of the leading States to address what is just horrific.

We now proceed to Mr. Langevin.

Mr. LANGEVIN. Thank you, Mr. Chairman. I thank our panel here, again, for your testimony here today and the work you are doing in these fields.

Admiral Winter, if I could start with you, can you discuss the relationship and the coordination efforts between ONR and the Strategic Capabilities Office when it comes to directed energy efforts. And certainly, I would like to also hear from our other witnesses how you are working with the Strategic Capabilities Office as well. But, Admiral, let's start with you if we could.

Admiral WINTER. Yes, sir. I am in a periodic contact with Dr. Will Roper, who is the head of the Strategic Capabilities Office, and geographically, they are one block down from my office. And we have continuous discussions about the technologies that ONR is bringing forward that I mentioned in my opening remarks across the spectrum of electric weapons and directed energy specifically, but others. And so we have a number of relationships and technological partnerships with the Strategic Capabilities Office. I will focus on the electric weapons and the directed energy to your question, sir.

Our work with the Strategic Capabilities Office is a partnership in requirements and funding to pursue the science and technology objectives of the Department of the Navy. Our Department of the Navy's strategic focus on laser and directed energy, so high energy laser and also high energy RF [radio frequency] technologies, to push forward to meet our Marine Corps and Navy objectives continues to move forward in marked progress, and moving forward, as I mentioned earlier. The Strategic Capabilities Office has come forward with their analysts and resources to provide us an oppor-

tunity to move faster and to move into different directions and partnerships.

From an electric weapon perspective, we are in partnership with them on our electromagnetic rail gun. But I don't consider that directed energy. I look at that as more as electric weaponry.

So right now, sir, those are the—that is our relationship. That is our engagement. The Strategic Capabilities Office provides those resources and guidance along the lines of the third offset strategy and other greater departmental warfighting capability analysis. And the Department of the Navy has the opportunity to partner and bring our resources to bear to help Dr. Roper and his team realize their mission.

Mr. LANGEVIN. Okay. We are not going to have—I am not going to have time, I don't think, to hear from everybody on that, but I would like to hear your feedback. Maybe you can respond in writing on how you are interacting with the Strategic Capabilities Office.

What I would like to ask for all of you, is directed energy a priority, and, in particular, is it a priority for the Department? I know many of you are working on these things. And, Admiral, you have talked about. But I want to know, is it a priority for the Department? Are they ready to accept these technologies once they have matured, and what technologies are maturing in this field? I think you talked about the *Ponce,* Admiral. So maybe from the other ones if we could hear your perspective on these things?

Mr. WELBY. Maybe I could start and we could move down the table quickly.

Mr. LANGEVIN. Yeah.

Mr. WELBY. Sir, I believe that today—you know, we have long had a conversation about directed energy being just 5 years off, and it has always been just 5 years off. And what—you know, I have a strong background in working directed energy programs. I think we are now today at a very different place, a place where those systems are now rapidly moving towards realization and are going to have impact on future military capabilities. Each of the services has efforts underway today. We heard about the *Ponce.* I will let Dave talk about some of the things that the Air Force is doing, particularly in advanced beam direction, I think, that are putting the other pieces together for real airborne lasers, and the opportunities in programs of record in areas like IFPC [indirect fire protection capability], where the Army is considering utilizing directed energy as a tool in the counter-rocket, artillery, mortar space.

I think we are now seeing application space emergence of capabilities, the breakthrough technologies, smart beam direction, realizable solid state lasers at high powers, 100 kilowatt plus kind of levels, and the ability to amass large numbers of fiber lasers coherently and to be able assemble and scale at a way that we just have not been able to do. All those—I am very excited about what is happening in each of those spaces. I'll turn it down the table.

Mr. LANGEVIN. Thank you.

Ms. MILLER. So the Army is committed to pursuing directed energy. Our high energy laser program within the Army S&T is demonstrating capability and has been used in an analysis of alternatives for the indirect fire protection capability program of record.

Right now, we are aligned to transition into that program of record in the 2023—fiscal year 2023 timeframe. Why that long? Because we are doing a step-wise demonstration of capability in the mission set of the Army. So we have to make sure that the lasers work and do the full set of scopes against the threats that we project. And those threats include the counter-rockets, artillery, and mortar, but also, UAV threats and cruise missile threats. We are trying to make sure that we understand, before we offer it to a soldier, what it can do and they understand its capabilities. And that is already planned in and funded.

Dr. WALKER. On the Air Force side, we have got a strong support for the Air Combat Command and our Air Force Special Operations Command [AFSOC] for integrating lasers defensively and offensively onto our aircraft in the future. Air Combat Command, together with the Air Force Research Lab, has commissioned the, what we call the Shield Advanced Technology demonstration to put a medium-powered laser, 30-kilowatt-class laser into a pod on a fighter aircraft to provide self-protection with the goal to grow the power as the devices grow in power. The Special Operations Command [SOCOM] has now commissioned both the Air Force Research Laboratory and the Navy at Dahlgren working with SOCOM to look at putting an offensive capability onto a AFSOC 130 gunship.

So that is a second one we are working. There is a lot of technology in beam steering and in power management, thermal management, that has to be worked in these that we are working under a considered S&T program with an eye toward transition on those two aircraft.

Mr. LANGEVIN. Very good. Thank you.

And with that, I know my time I have gone over, and I know Mr. Lamborn has similar questions, my co-chair of the Directed Energy Caucus. So in that case, I will yield back, Mr. Chairman, and thank you.

Mr. KLINE. Thank you, Mr. Langevin. And now we will proceed to your teammate, Congressman Doug Lamborn of Colorado.

Mr. LAMBORN. Thank you. And I thank the co-chairman of the Directed Energy Caucus, Representative Langevin of Rhode Island, for beginning this subject. It is such an important subject. And I am just going to build on what he has already asked.

How do you all make sure that you are not duplicating what each other is doing? I see three centers of important research of making things operational, not to mention DARPA. And so—and I don't know if that is for you, Mr. Welby, or for the individual branches to respond to. But how do we make sure that there is no duplication, you know, no reinventing the wheel going on, whether it is directed energy or anything?

Mr. WELBY. If I could quickly, I think this is a great area where we can demonstrate kind of solid cooperation coordination through S&T and across the services. The High Energy Laser Joint Technology Office serves as a clearinghouse and a center for coordination across all the efforts across the Department. And that allows us to ensure that each of our investments are aligned, not duplicative, and are building on each other. And I think that in each of the domains, there are service-unique issues. So it is with how

those will be hosted on future platforms. But there is also supporting technology that services all those needs. And we very well coordinate, I think, in this space, across all those areas. And I will turn it back——

Mr. LAMBORN. And, Ms. Miller, I see that you have been working on this for 30 years. So—and, Admiral, did you want to respond to that as well?

Admiral WINTER. Not to the 30-year question, sir, but the center—the center—the communities of interest that the Department has established that allows the services and DARPA to come forward in functional areas allows us to share our resources, our research, and our efforts, not specifically for directed energy, but across the board, that allows us to see what I call common, cousin, and unique efforts. And there is some benefit in common research where it is appropriate. But as Mr. Welby mentioned, our uniquenesses for maritime shipboard applications, for example, and also looking at underwater directed energy applications, there is challenges in that. And so our efforts that go forward are looked at the Navy uniquenesses. I am very—sitting here now one year downrange, very satisfied that we collectively—we meet once a month at the senior level, and we have working group that meets once a week to talk across our span of 6.1, 6.2, and 6.3 research to understand where we can leverage off of each other. And not only within the Department of Defense, but with our industry partners, academia, and our other interagency folks.

Mr. LAMBORN. Mrs. Miller, would you agree that we are—like Mr. Welby has already said, that we are—it is not something that is always 5 years off, that we are now getting a lot closer, if not actually there, with operational directed energy weapons?

Ms. MILLER. I believe——

Mr. LAMBORN. Defensive and offensive.

Ms. MILLER [continuing]. I believe we are very close. And I think right now what we need to do is build trust with our operators so they understand what lasers can do. Lasers have been promised for an awful long time, and they have never held up and delivered what was asked for. And so the operators are quite rightfully skeptical, which is why you see the services taking laser out in operational environments and letting them be used by operators so they understand what the capabilities are.

I think we are very close. And while we are looking at the large capabilities that these can provide, there will be steps along the way where we will spin out lesser capable laser systems that can do good things on smaller platforms, and that is something that you will see coming out relatively soon.

Dr. WALKER. A couple of things on that, sir. The Air Force every day is flying with lasers under our large aircraft, infrared countermeasure system. So we have done exactly that. We have spun out lower-powered lasers that gave us the capability to protect our aircraft, flying in theater today. The goal is to build off the experiences that we have had there to, as we get larger power outputs, better thermal management out of smaller packaged lasers to be able to transition these to other aircraft besides our large transport aircraft. And as we build those powers eventually moving defensive

capability to using that same laser to give us offensive capability as well.

So I think we are on a good path. The move to electronic lasers has allowed us to do that. The other point is, one of the reasons that we are able to do this well across the services, is that we have a joint technology office that really works those fundamental laser technologies for us as a joint team that we then spin off each into our own particular areas, our domains for usage. And having that office support, what we need as the three of us sit on the advisory panel to determine what they are going to actually invest the funds in, make sure that they are meeting our needs as a service.

And the last piece is our partnership with DARPA has really allowed to us move lasers forward, moving the slab lasers, electric lasers, and moving into fiber lasers. DARPA has been a key partner in allowing us to do that.

Mr. LAMBORN. I appreciate the work that you are all doing. Thank you, Mr. Chairman.

Mr. WILSON. And thank you co-chairman Lamborn. We now proceed to Congressman Marc Veasey of Texas.

Mr. VEASEY. Thank you, Mr. Chairman. I wanted to specifically ask you about talent as it relates to implementing a lot of this new technology. Of course, you know that the Secretary has visited Silicon Valley and talked with the executives there. How does the Department tap into these smaller companies, because so much of what has happened in Silicon Valley and the technology that we are using today, and so much of the technology that our enemies around the world are using, I mean, we have been following this deal with not being able to unlock the iPhone.

How does the Department tap into the technology that may be available from some of these smaller companies that aren't necessarily coming up through some of the larger defense corporations and things like that that we normally use? Anybody that wants to answer that, it would be great.

Mr. WELBY. Let me start, again, and pass it down the table. I think we have a number of tools that we use I think very effectively to engage small innovative business. And small business is often the key engine for innovation. Traditional tools, like our Small Business Innovative Research program, our STTR [Small Business Technology Transfer] program, and tools like the Rapid Innovation Fund, which has a very large portion of small business engaged in rapidly moving contracts that can be rapidly exploited, moving technology to application.

The Secretary has been committed to trying, opening the Department to new sources of innovation. He has been out engaging small companies in Boston, and on the West Coast, will happen in other parts of the country here shortly, personally demonstrating the importance of the Department engaging with small innovative business to think through ways that we can couple what they are working on with the needs of the Department.

I spent a day last week out at our DIUx facility in Mountain View, where we had an afternoon and invited small innovative companies in to come talk to us. And we had over 200 companies show up at that meeting. I spent 2 hours in one-on-ones with small companies afterwards. A lot of these folks don't want to be called

small companies, of course, because they want to be the next big thing and they take that as a bit of a—but it is really kind of remarkable sets of ideas. Traditionally, the challenge has been trying to connect those back to the needs of the Department, and many of these companies don't have the time, energy, connections, background knowledge to be able to make those kind of connections.

And the question earlier was what are we trying to do with DIUx, part of it is to take that burden off of those companies and to allow some of our smart folks to serve as shepherds, if you will, to serve as ambassadors to connect those folks who have ideas, who have new emerging technology, often focused at a commercial market, and connect them with people in the Department who could really apply that.

And so we have got folks sitting out in that facility in Mountain View today who understand a lot about the needs of the Department. They spend a lot of time talking to small innovative businesses, and they are trying to make those connections every day. We think that is going to help us accelerate the process. It is a people thing, as well as simply the kind of making sure we have dollars and contracting vehicles in place.

Mr. VEASEY. Yes, and let me ask you another question along the lines as far as innovation and technology. You know, one of the things that has been brought up also is retaining talent, the Pentagon being able to retain talent because Silicon Valley and other tech centers can pay so much more. Just from a budgetary standpoint, do you think that as far as retaining that talent, that maybe we need to look at paying those people more? And let me give you an example of what I mean by that. Like, for instance, in State government, like in the State that I am from, or the State that Mr. Aguilar is from, where you have large pension funds. The people that actually are the State employees that run those pension funds are usually the highest paid employees. They make a lot more than the Governor makes.

Do you think that there should be some sort of a, you know, carve-out for individuals, because this is obviously going to be high priority with our enemies being able to more and more use this technology to try to harm us; that we should have some kind of a carve-out that will allow us to pay the people that have this expertise and keep them at the Pentagon?

Mr. WELBY. Sir, I don't want to keep them at the Pentagon. I want to keep them out in our laboratories where they are going to make those real compelling changes. But the thing I do worry about is talent. The thing that keeps me up at night is talent. And I am very excited that under the "Force of the Future" personnel initiatives that the Secretary has initiated, we are now talking about talent management, talent retention, recruiting, using kind of commercial recruiters as ways to get access to key talent.

I don't worry that—in the government, it is going to be very difficult for us to compete dollar for dollar in terms of salary with folks. I note that last week, the National Engineering Salary Survey came out, and I noted that the average salary, not the talent that we are looking for, but kind of average over the engineering professionals in the United States, the typical pay increase was 7.5

percent over the last year. We haven't seen a 7.5 percent increase in government I don't think ever.

So I mean, every year we kind of fall behind in terms of that offer we are able to make people. But people don't come to work for us because of the pay. Historically, people came to work for the government because of stability, but the current generation doesn't want stability. What they want is opportunity. And we offer, in many of the laboratories and many of our critical areas, the ability to make a difference, a mission that is compelling, an access to key technical tools, and in some areas, we are competing directly with the best for cutting-edge talent.

I worry though, in some areas, biotechnology, in artificial intelligence, computer science, robotics, we are in a strict competition for talent. And I watch those areas very closely, and the folks that I have on my short list of our best, I see more leaving than coming in. So we are working hard to kind of focus our recruiting efforts in that area. We are thinking about what we can do to augment those people with contract and support or other mechanisms that we can have. But any flexibility in people I think is going to be critically important in the future.

Dr. PRABHAKAR. I know we are late on time. I would like to just tag on one small comment. A very specific thing that we use all the time is the special hiring authority that this committee originated in 1999, and has extended over and over again. It is called the 1101 authority. It gives DARPA a little bit of flexibility in salary levels; not nearly enough to compete head on, but exactly, as Steve said, it makes it not completely impossible to go after some of these amazing people.

But that authority is vital to our ability to bring in amazing people and we do regularly compete against staggeringly large number salary offers that our candidates are getting, and we are able to get them because they want to come change the world from DARPA. But the specific thing that this committee has an opportunity that can make a huge difference, is that 1101 authority has been an experimental authority now for 16 years. I think the experiment has really proven out, and I would ask for your support to make that a permanent option for hiring as we go forward.

Mr. VEASEY. Thank you.

Dr. WALKER. I would also like to weigh in on it. One of the things that really allows us to attract top talent is some of our scholarship capabilities, and the SMART program has been one that has been exceedingly successful for the Air Force and for the other services. One of the keys to retaining talent is getting them into the laboratory and getting them the opportunity to actually operate in the laboratory and have the freedom they get and the magnitude of responsibility they get within the government laboratories. The SMART program is a way to bring them in and then to continue to educate them as they move forward, and, so, that is one of the ways we have been able to bring in top talent, and so far, we have been retaining about 87 percent of our SMART-educated folks, once their government service mandate is up. So, that has been very successful. I would like to continue that one.

Mr. VEASEY. Thank you. Mr. Chairman, thank you very much.

Mr. WILSON. Thank you, Mr. Veasey. We now proceed to Congressman Pete Aguilar of California.

Mr. AGUILAR. Thank you, Mr. Chairman, I appreciate the opportunity, and I had similar questions to Mr. Veasey related to your ranks and pipeline and the number of researchers we have. And I know out of the material that was one of the takeaways that I had is continuing to offer that flexibility and the resources that you have in order to attract and retain those who are at the laboratory level working hard for us.

You know, we heard a little bit about directed energy, and within S&T, if you folks, you know, I may be the last questioner here, so, you know, within your crystal ball, if you were talking to your predecessor, or, I am sorry, your successor, you know, 10, 20 years down the line, what areas do you think this committee and those individuals will be working on? And I say that, Mr. Welby, you know, you talked about small businesses, and those in the outside world who were thinking about big ideas, and, but I mean, I look across this table, and what you have done in government, the five of you, you know, you are our innovators, and you are our line to, you know, weigh and discuss these issues of importance that are going to help protect and defend this country.

And, so, I would just like to hear a few ideas or examples of things that you feel you would be talking to your successors about, you know, down the line if you were crystal balling looking at areas that this committee may have to weigh in on.

Mr. WELBY. Let me quick start. Sir, I've had the opportunity to kind of spend my life thinking about that future, trying to live in that future, trying to predict what those things that will matter will be. When I look across what is being invested in by my colleagues and the folks within the Department, I see four areas I will just bring up. There are many more. But I will go through these very quickly.

One is unmanned and autonomous systems, the work that is going on in the Navy in unmanned undersea vehicles and the DARPA work in unmanned surface vehicles, the work going on in swarming air vehicles. I think we are going to see a lot of—a very fundamental change from the baby steps we have taken in that space today to a very different world in the future.

I see a real opportunity as we come to the end of Moore's law where we have been able to predict microprocessor change over time, seeing explosion in new capabilities. We built industries on the predictability of Moore's law, which is coming to an end and it is going to create new opportunities. I think that we are going to see biology as a technology, a major push of DARPA's start to shape the world in fundamental ways. We need to think about that. That is an area for which the Department is not as strong as we could be. We need to start thinking about how we build our biological technology capabilities; not just—we think about biochem defense, but really, biology, for example, as a manufacturing science.

And then thinking about that last topic, manufacturing, what is the future of manufacturing and design? How will we be delivering capability in the future? How will it be stanching that capability to advanced systems? I think that that list is interesting because

those four things are not going to be unique to defense. All of them are going to have commercial implications and we need to be—if I tell my folks, we want to be able to surf the coming wave in these areas, but to be a good surfer, you have to be out in front of that wave paddling in front of it. And we need to be smart getting out in front of that before those things hit. And so that is my short list anyway, sir.

Ms. MILLER. So he had four critical ones and in the area of autonomy, you know, we are looking at intelligence systems and how we can get the capability to interface autonomous capability with humans and make sure that we have a seamless way to provide kind of design for individual capability, be it training, be it operating systems that scenario that goes into the biological sciences that we are not usually accustomed to. And so when we talk about building our workforce and giving them interesting dilemmas to bring them into our team to work for the Department of Defense, that is one of those areas that we are building up our expertise because we see that as critical for the future going forward.

Admiral WINTER. Sir, I just have to look at 30 years ago what was in our petri dish and test tubes that we are fighting with today. So what should be in our petri dish and test tubes today that we are going to be fighting with in 30 years that I would tell to my successor. I look at areas of brain-based learning, understanding the true neuroscience of human thinking and how we can model that into an engineering model that will allow us to truly realize cognitive artificial intelligence of man-machine capabilities. That is one area.

Breakthrough in our nano and photonic domain, of being able to process and transmit data at rates that are just unfathomable today, based upon advanced material science and bringing that together to then enable that cognitive AI [artificial intelligence] and man-based and machine capabilities to levels we haven't even thought about, Terminators, those type of things, moving forward.

And then from a bio-inspired perspective, the advances in our synthetic biology of being able to craft organisms that can eat ferro metallic material and excrete electricity in any domain, undersea, a vacuum, allows us to start to think of the possibilities of endless supplies of energy. Endless supplies of energy are things that people scoff at, but the scientists are the ones that are supposed to be doing the things that are scoffed at. So I see areas in brain-based learning, our bio-inspired technologies, our cognitive IA, advanced materials, and photonics and nano areas. Thank you, sir.

Dr. WALKER. I have to say that we are all looking down the same path. One of the areas I really see promise that in 20 years from now, I would hope to be actually the state of the art is really the science of the very small. Is how do we take advantage of nanomaterials, quantum effects, metamaterials, and then how do we link that with biological agents that actually help us manufacture those materials in a very effective way.

There is a lot of promise in that area that I think we will see in the future will move us into being able to build materials that we don't even conceive at this point in time. The other areas which Mr. Welby hit on was manufacturing is fundamentally changing. And we are not going to see large factories in the future like we

are used to today. We are going to see the ability to actually grow things and other manufacturing technologies that will allow us to get our economic order quantities down to the order of one, which will fundamentally change how we do business where we don't have to buy 1,000 to be effective.

And the final one is in autonomy. We are just scratching the surface with autonomy and aiding humans. Autonomous decision-making to aid humans to be able to execute warfighting from a distance. We are seeing it now in its very infancy. Twenty years from now, we will just see this as everyday. You will see that every day when you get in your car and your car takes you where you want to go, and parks you where you need to be, and you read your iPad the entire time you are going there.

Dr. PRABHAKAR. These are all great answers. I think they are terrific. Let me add one different kind of log on the fire. There is something happening with social behavior with the Internet, the Internet of Things and social media. And social behavior itself is changing, but also how we can look at and understand social behavior is changing in some fundamental ways. It is going to, in the next 10 or 20 years, I think it is going to give us even bigger headaches than we already see. We are going to have privacy headaches. We are going to have information warfare headaches. We see that today. I think those are going to get worse over time. But at the same time, what is happening is, I think there is going to be a fundamental shift in our ability to understand social behavior. And I would submit that there is actually nothing more fundamental to national security than that.

Mr. AGUILAR. Thank you, Mr. Chairman.

Mr. WILSON. And thank you, Mr. Aguilar. And Dr. Prabhakar, the, as you have said, headaches, I was hoping with the Internet, it would be opportunity.

Dr. PRABHAKAR. Both.

Mr. WILSON. And it should be both, but sadly, recently I have seen more headaches than I have seen opportunity. And so we are counting on you to figure out how to address the headaches. So again, I am very grateful for each of you for your service. And there being no further business, and upon the advice of Mr. Langevin, we are now adjourned.

[Whereupon, at 3:26 p.m., the subcommittee was adjourned.]

A P P E N D I X

FEBRUARY 24, 2016

PREPARED STATEMENTS SUBMITTED FOR THE RECORD

FEBRUARY 24, 2016

Chairman Wilson Opening Statement
Hearing:
"Department of Defense (DOD) Fiscal Year 2017 Science and Technology Programs: Defense Innovation to Create the Future Military Force"
February 24th 2016, 2:00pm, 2212

I call this hearing of the Emerging Threats and Capabilities subcommittee of the House Armed Services Committee to order.

I am pleased to welcome everyone here today for this hearing on the Fiscal Year 2017 Budget Request for science and technology programs within the Department of Defense.

In a recent speech, Secretary of Defense Ash Carter spoke about the return of great-power competition, and the need to deter our most advanced competitors. We can only deter these competitors and adversaries when the Department of Defense harnesses innovation and creates new capabilities for the military that will maintain and expand our tech-superiority, now and into the future to achieve peace through strength.

This budget request is a good step in tackling the modernization challenges of the Department. Activities like the Third Offset Strategy and the Long Range Research and Development Plan are important to charting a course that takes a strategic view of the security environment; however, I remain concerned that it is too little too late. As I see it, starting major initiatives at the end of an administration makes it difficult to ensure that these things will survive the new budgetary and policy priorities that will naturally arise with a new President. I hope I am wrong, since I support many of the things being proposed in this budget request, but only time will tell.

I would like to welcome our distinguished panel of witnesses, and appreciate their perspectives on all of these issues. This panel includes:

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

Ms. Mary Miller, Deputy Assistant Secretary of the Army for Research and Technology

Rear Admiral Mat Winter, USN, Chief of Naval Research

Dr. David Walker, Deputy Assistant Secretary of the Air Force for Science, Technology, and Engineering

Dr. Arati Prabhakar, Director, Defense Advanced Research Projects Agency

I'd like to turn now to my friend and Ranking Member, Mr. Jim Langevin from Rhode Island, for any comments he'd like to make.

Statement by Mr. Stephen Welby

Assistant Secretary of Defense for Research and Engineering (ASD(R&E))

Before the

Subcommittee on Emerging Threats and Capabilities,
Armed Services Committee, U.S. House of Representatives

Department of Defense Fiscal Year 2017 Science and Technology Programs:
Defense Innovation to Create the Future Military Force

February 24, 2016

NOT FOR PUBLICATION UNTIL RELEASED BY THE SUBCOMMITTEE

Accelerating the Development of Military Capability through Innovative Defense Research and Development

Introduction

Chairman Wilson, Ranking Member Langevin, and Members of the Subcommittee, I am pleased to have the opportunity to provide testimony on the Department of Defense (DoD) Fiscal Year 2017 Science and Technology (S&T) program and to join my colleagues from across the Services and DARPA to report on the current state of S&T in the Department. Defense S&T enables our nation to sustain the technological advantage that underpins our ability to successfully execute the Department's mission. The DoD S&T program delivers a balanced technology investment, informed by an awareness of global technology trends and critical threat capabilities, and supports the three tenets of the Department's research and engineering strategy: to provide technology to mitigate current and anticipated threat capabilities, to affordably enable new or extended capabilities in existing military systems and to create technology surprise through advanced capabilities that significantly expand our capabilities.

Key to our S&T success is our investment in our people – the talented scientists and engineers who perform the complex, state-of-the-art research, development and engineering required to ensure America's future technological superiority in an increasingly competitive global security environment. With their colleagues in academia and industry, our defense S&T workforce is engaged every day in developing the capabilities that our nation's warfighters will need tomorrow.

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) is 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, maintain international norms, and support 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.

Today, our brightest young scientists and engineers are pursuing these technology innovations by leveraging new and emerging capabilities in material science, advanced electronics, computational algorithms, quantum sciences, biology and health sciences, advanced optics, robotics, artificial intelligence, and other disciplines and applying these technologies to create improved military capabilities informed by operational experience and needs.

As any surfer knows, the only way to catch and ride a wave is to paddle out in front of the surge; catching a wave from behind does not work. The same is true with technology. In a fast changing technology environment, the Department must be positioned to understand, shape and exploit technological opportunity to its best advantage for application to military systems. The Department must carefully select those areas where we must invest to lead technology development. We must also identify those areas where we want to partner with academia, industry and our international partners in shaping technology development. By engaging early, DoD can shape the technology environment and drive a focus on speed from lab to field.

Driving Innovation

Our Department-wide focus on technology innovation seeks to identify and invest in unique capabilities to sustain and advance the Department's military superiority for the 21st Century. As Secretary Carter said in his remarks on the budget at the Economic Club of Washington, D.C. on the 2nd of February, we must take a "long view" and "seize opportunities for the future" in order to "sustain our lead in full spectrum war fighting".

In an increasingly competitive and fast moving technology environment, the Department must be open to all sources of competitive technical advantage and must engage with traditional and non-traditional sources of capability both internal and external to the Department.

Today, the Department employs over 39,000 scientists and engineers in 63 Defense laboratories, warfare centers, and engineering centers across 22 states sustaining our ability to support and field military critical technology that often has no commercial equivalent. Our laboratories have produced important innovations in vital defense areas such as electronic warfare, propulsion, and weapons design and maintaining this unique technical expertise is critical for ensuring the Department's ability to prepare for future threats. However, we cannot innovate and bolster our future technological superiority from within the Department alone; our Defense laboratory enterprise touches the broadest range of emerging concepts through a deep engagement with academia, industry, and international partners to keep the DoD smart, knowledgeable, agile, and responsive in the face of new and emerging threats. This includes outreach to a vibrant and growing commercial innovation community that sometimes does not consider applying their emerging technologies to the national security sphere. In Fiscal Year 2015 DoD's research and engineering enterprise established over 2,000 cooperative research and development agreements with private companies or universities and filed over 875 patents.

In fast moving areas, investments made by the commercial entrepreneurial sector are accelerating the development and maturation of technologies with critical relevance to future defense capabilities. Often, small innovative commercial firms lack knowledge about the defense systems, organizations, and problems that could benefit from their products and technology. They are also often unwilling to invest their scarce time and resources in identifying DoD customers for their work and unable to navigate the DoD acquisition system. The Department has begun efforts to address these challenges and recently established the Defense Innovation Unit-Experimental (DIUx) with an initial operating location in Silicon Valley, California. DIUx is experimenting with new approaches to serve as an "point of presence" connecting the Department with non-traditional technology and capability sources by scouting for capabilities relevant to military needs and by matchmaking DoD customers with potential sources of advanced capabilities from innovative commercial entrepreneurs.

Driving Value to the Warfighter through Science and Technology

The Department is committed to sustaining our technological advantage and maintaining our long term technological superiority. Over the last year we have continued to make progress strengthening both our internal capabilities and our connections to external innovation centers. Some representative activities of note from 2015 include:

The Department of Defense played a critical role in supporting the US government and international response to the West African Ebola outbreak to support Ebola planning and response efforts. From the earliest days of the outbreak, DoD S&T personnel worked tirelessly to deliver critical equipment and supplies to the affected West African countries. The Department deployed and sustained Ebola diagnostics laboratories to Liberia and Sierra Leone and provided timely technical subject matter expertise and advice to the Task Force on Ebola Response, the Combatant Commanders, interagency partners, and international partners. The Department also contributed to the development of Ebola-specific detection technologies, developed breakthroughs in medical countermeasures and bio-containment transport systems, and provided knowledge management tools to aid decision-makers. DoD efforts helped curb the spread of Ebola virus in West Africa, saved lives, and contributed to building sustainable bio-surveillance and public health capacity in the region.

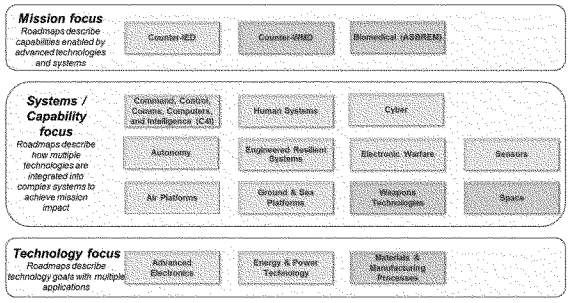
In 2015, the Department continued to focus efforts on developing advanced capabilities to address emerging electronic warfare (EW) challenges, to evaluate these capabilities and to mature them for future operational adoption. One example of these efforts was the successful Vigilant Hammer experimentation campaign. The Vigilant Hammer provided a cost effective, joint opportunity to explore and assess US emerging capabilities to fight in a complex, congested, and agile electromagnetic spectrum. Vigilant Hammer provided the S&T community with unprecedented access to the representative dense signal environment in which US systems will operate in the future.

In May 2015, the Deputy Secretary of Defense hosted the first-ever DoD Lab Day at the Pentagon, which showcased more than 100 Air Force, Army, Navy, Marine Corps, and DoD Medical innovations designed to ensure the future technological superiority of our nation's military. DoD Lab Day increased awareness and understanding of the complexity and diversity of the DoD Lab enterprise and highlighted the contributions that DoD labs made in providing vital support to missions as diverse as global disaster relief, defensive cyber protection, chemical and biological defense' and counter improved explosive devices.

In order to ensure we remain at the forefront of S&T we must also be connected to the global community by continuing to forge relationships with our international partners. The DoD S&T community continues to engage globally with allies and partners and with key academic and technology institutions worldwide. Among our global engagements, we continue to support multilateral S&T cooperation through the NATO alliance and through The Technical Cooperation Program (TTCP) with the United Kingdom, Canada, Australia and New Zealand. The Department continues productive bilateral S&T cooperation, and in the last few weeks have concluded annual reviews of on-going collaborative S&T efforts with a number of partner nations. As an example of the benefits of the cooperation, the US/UK Multi-disciplinary University Initiative (MURI) effort supports projects that are competitively selected with DoD supporting US Academic institutions and the UK Ministry of Defense (MoD) supporting UK researchers who then collaborate in areas of mutual US DoD and UK MoD interest. We have also continued to focus on strengthening US-India defense cooperation. Over the past year, the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) has sponsored five workshops with India covering a wide-range of areas of mutual interest: cognitive sciences; autonomy; directed energy; materials; and munitions (including Counter-improvised explosive devices). Over 30 potential S&T projects from these workshops are currently under consideration for co-development.

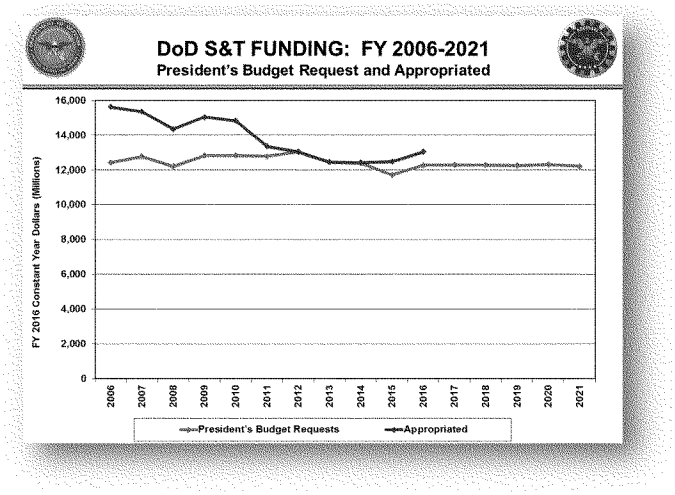
As we execute our plans for the rest of this fiscal year and into Fiscal Year 2017, ASD(R&E) continues to provide oversight of the Department's comprehensive S&T investment portfolio through the Reliance 21 framework. Reliance 21 provides a forum to synchronize, coordinate, and deconflict Service and Agency S&T activities. In the last year, we improved joint planning and coordination of S&T activities among the Department's senior S&T leadership to achieve efficiencies and improve the effectiveness of our support to the Operating force. This collaborative process captures the interests and activities of the entire R&E enterprise and all our partners in a collection of 17 Communities of Interest (COIs). The COIs maintain awareness of their portfolio areas by reviewing and assessing the alignment of current and planned R&E programs, identifying gaps, and helping to prioritize R&E funding efforts to meet the technical challenges of the DoD in their respective portfolio area. Each Reliance 21 COI represents specific cross-domain technology areas with a rotating steering group lead and draws upon subject-matter experts from across the Department working in the relevant technology area.

The Reliance 21 framework, its S&T Executive Committee, and technology area COIs are key mechanisms that support ASD(R&E) integrated oversight of the Department's S&T investments.



Fiscal Year 2017 Budget Submission

The President's Fiscal Year 2017 Budget submission continues to demonstrate strong support for sustaining a robust DoD S&T investment to ensure that the Department is developing the innovative technological capabilities that will inform future capability options and sustain US technological superiority. The chart below depicts DoD funding over the last decade and as proposed in the current budget submission over the Future Year Defense Program.



As evidence of this commitment to a strong DoD S&T capability and capacity, the Fiscal Year 2017 budget request for overall S&T is $12.5 billion; 1.9 percent above the Fiscal Year 2016 budget request and 2.4 percent of the Defense topline ($524 billion). In real terms, the Fiscal Year 2017 S&T budget request is 25 percent higher than the Fiscal Year 2000 budget request of $9.8 billion. The table below details the proposed DoD S&T budget by year and breaks out investment by budget category and by S&T account.

Table 1. FY 2015 - FY 2021 Budget ($ Millions)

Program	FY 2015*	FY 2016**	FY 2017	Δ FY16-17	FY 2018	FY 2019	FY 2020	FY 2021	Total FY17-21
Basic Research (6.1)	2,277.7	2,088.9	2,101.8	12.9	2,228.3	2,268.4	2,302.6	2,329.0	11,230.2
Applied Research (6.2)	4,647.8	4,713.2	4,815.4	102.2	4,961.5	5,048.4	5,136.3	5,221.1	25,182.6
Adv Tech Dev (6.3)	5,326.3	5,464.2	5,583.5	119.3	5,565.8	5,665.1	5,860.0	5,890.9	28,565.4
TOTAL S&T	**12,251.8**	**12,266.3**	**12,500.8**	**234.4**	**12,755.7**	**12,981.8**	**13,298.8**	**13,441.1**	**64,978.1**
Army S&T	2,554.8	2,200.5	2,266.6	66.1	2,321.1	2,371.2	2,425.2	2,475.4	11,859.4
Navy S&T	2,155.3	2,114.4	2,141.1	26.7	2,168.3	2,176.3	2,205.8	2,237.6	10,929.0
Air Force S&T	2,281.7	2,378.4	2,486.0	107.6	2,571.3	2,634.2	2,756.0	2,701.5	13,148.9
Defense-Wide S&T	5,260.0	5,573.1	5,607.1	34.0	5,694.9	5,800.2	5,911.9	6,026.6	29,040.7
TOTAL	**12,251.8**	**12,266.3**	**12,500.8**	**234.4**	**12,755.7**	**12,981.8**	**13,298.8**	**13,441.1**	**64,978.1**

Source (FY2017 -FY2021): CIS 5 January 2016

** FY 2015 Enacted (base), no OCO*

*** FY 2016 President's Budget (base), no OCO*

- The Fiscal Year 2017 S&T budget request includes a $12.9M growth from the Fiscal Year 2016 budget request in Basic Research investment to $2.102B. Much of this investment supports the Department's engagement with academic institutions in the foundational research efforts that drive future innovation.
- The proposed 2017 S&T budget includes a $102.2M growth from the Fiscal Year 2016 budget request in Applied Research investment to $4.815B.
- The proposed 2017 S&T budget includes a$119.3M growth from the Fiscal Year 2016 budget request in Advanced Technology Development investment to $5.584B. Additional investment increases an emphasis on prototyping and experimentation to reduce program risk.

The Department's Fiscal Year 2017 S&T budget request is aligned with DoD priorities that supports increased demonstrations and increased efficiency in our DoD-wide S&T program while preparing the Department for a competitive global security environment.

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: capabilities such as long range precision weapons, airborne ISR for real time targeting, network centric integration of command and control and strike, 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 he 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 directly to 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 innovation 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. And 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 United States 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 likely 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 interface 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.

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

In recent presentations, the Deputy Secretary of Defense has pointed to several areas where he sees significant opportunity for advanced technology to advance differentiating US capabilities:

- Autonomous, Learning Systems – systems capable of manipulating and understanding large volumes data, and/or that have the delegated authority to support or make decisions within delegated limits under operational control , especially in application areas that require faster than human reaction times (e.g., cyber defense; EW attacks; missile defense; and active protective systems);
- Human-Machine Collaboration and Manned-Unmanned Combat Teaming – systems that team humans with machines to exploit the advantages of both for better and faster human decision making;
- Assisted Human Operations –systems that directly support humans to perform better in combat (e.g., wearable electronics and integrates software applications); and
- Advanced Weapon Systems hardened to operate in complex Cyber and Electronic Warfare (EW) Environments – systems that can communicate, coordinate and communicate with each other in mission, in complex threat environments to achieve synergistic effects.

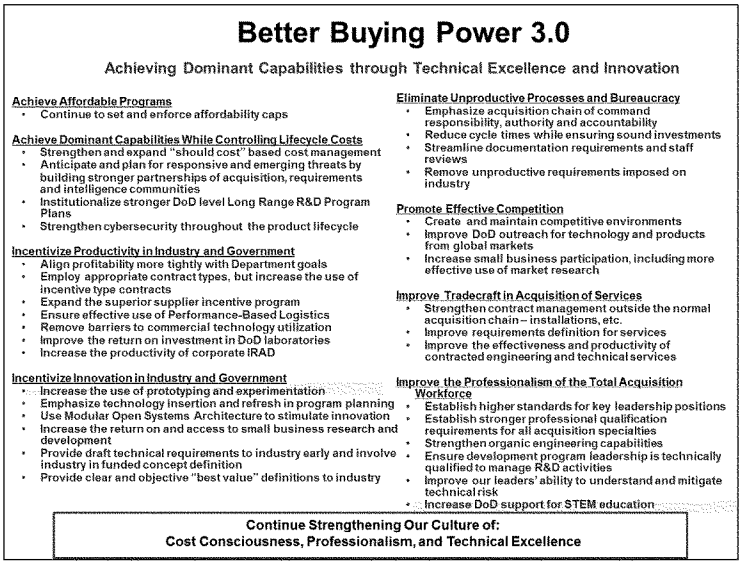
In 2015, the Department conducted a classified long range research and development planning program (LRRDPP) to identify critical technologies and future system concepts that the department should consider to inform material operations for the future force. The Fiscal Year 2017 budget is informed by the LRRDPP study and other analysis efforts and includes more than $3.6 billion in Fiscal Year 2017 and $18 billion over the Future Year Defense Plans to help spur research, development, test, evaluation, and procurement of advanced capabilities that will enable future offset strategies that our military will need to deter and, if necessary, fight and win high-end conflicts in the future. While relatively modest compared to the Department's overall program, these investments will enable the development of leading-edge, primarily asymmetric capabilities and help spur development of new ways of warfighting to counter advanced adversaries.

These investments 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 importance of focusing on cost so that we will be able to introduce asymmetric capabilities into the Joint Force at scale.

Our S&T investments ultimately are reflected in the capabilities embedded in material systems that are acquired, fielded, and operated by our fighting forces. For the last six years, the Department has been engaged in a major campaign to improve our acquisition processes. Originally initiated by then Under Secretary for Acquisition, Technology and Logistics Ashton

Carter and continued under current USD(AT&L) Frank Kendall, the Better Buying Power initiatives reduce unnecessary rules and regulations, eliminate unproductive processes, strengthen the acquisition chain of command, and align incentives with performance. The latest iteration of Better Buying Power 3.0 has as its principal focus on "Achieving Dominant Capabilities through Technical Excellence and Innovation." This focus reflects the criticality of the research and engineering components of the acquisition community in sustaining US technological superiority and emphasizes the need to support a strong, effective and productive DoD laboratory enterprise to foster continuous improvement across the research and engineering community.

Two areas emphasized in Better Buying Power 3.0 are 1) the use of prototyping and experimentation to accelerate operational assessment and adoption of key technologies to advance current and future weapons systems and 2) support for a robust DoD STEM engagement to ensure a pool of defense relevant technical talent to support our future force.



We are placing a strategic emphasis on prototyping and experimentation to identify emerging capabilities and unanticipated threats and reduce risk in DoD acquisition efforts. We are using prototyping supplemented by engineering analysis to evaluate new concepts, guide new technology development, and demonstrate new capability. Prototyping may permit the Department to explore the realm of the possible without a commitment to follow-on

procurement. Other benefits of our investments in prototyping include the ability to sustain unique elements of the defense industrial base, stimulate design teams to advance the state of the practice, improve development methods and manufacturing, and promote open standards, and competition throughout the product lifecycle. Our analysis efforts use scenario-based, engineering informed, excursions of emerging technologies and potential operational concepts to inform the requirements, acquisition and warfighter communities.

We also support our forces at the tip of the spear with technology solutions and timely analysis of demonstrations targeted towards critical system solutions. The ASD(R&E) Emerging Capability and Prototyping Directorate is engaged with the Combatant Commanders (COCOMs) and the Service technology and acquisition communities to exploit innovative demonstrations through Joint Capabilities and Technology Demonstrations and other programs that support COCOM concerns and warfighter needs.

Balancing the near- and far-term missions of our military with the rapid rate of technology turnover drives complexity in the engineering, testing, and evaluation of our defense systems. Systems engineering and testing are among the Department's strengths; however, the traditional practices of engineering and tests are challenged not only by the scale and operational tempo of the national security enterprise but by additional factors that include fiscal and budgetary constraints; the evolution and globalization of advanced technology and software; the necessary integration of complementary systems to achieve mission effects; and the responsibility to provide a safe, secure military capability that is ensured to perform as expected. These factors translate into design and performance demands for our engineers and testers in terms of resilience, affordability, interoperability, reliability, safety, and security. We continue to focus on ensuring a robust engineering and test competency and practice across the Department, as this capability remains critical to program success.

Our Research and Engineering enterprise also supports national leadership by engaging with, and shaping the national and international RDT&E environment through our STEM efforts, workforce programs, community outreach, international programs and our support for inter-agency efforts. By teaming with our strategic partners, the Department is taking steps to sustain and strengthen our critical organic workforce capabilities and broaden our partnerships with commercial and defense industry, universities, and federally funded research and development centers to augment our workforce with their talented workforces. As the Nation's largest employer of scientists and engineers, we are concerned with the younger generations falling test scores and global competition for STEM talent. DoD is fully engaged in a national effort to reverse the declining trends in the STEM student population. While focused on defense specific needs, we are partnering with other agencies and local communities, and, most importantly, our own STEM workforce to fully engage students, teachers, and family members with a goal of building a 21st century STEM workforce that will ensure the US remains the world's leader in defense innovation. Two critical STEM efforts are the Departments Science, Mathematics, and Research for Transformation (SMART) Scholarship Program and Military Child program.

SMART is our flagship scholarship-for-service program designed to produce the next generation of Department of Defense laboratory science and technology leaders. The program was identified by the Secretary of Defense as a critical workforce enabler and is included in the DoD's Force of the Future initiative. SMART offers highly competitive scholarships to undergraduate, masters, and doctoral students who have a demonstrated ability and aptitude for excelling in the scientific and engineering fields critical to the Department. Students receiving SMART scholarships commit to a period of employment within the DoD research and engineering community commensurate with the fiscal investment made by the Department in their education. In Fiscal Year 2015, the DoD awarded 207 scholarships adding to the 456 scholars currently in academic pursuit, and hired 167 SMART graduates into the workforce adding to the 485 already serving their commitment. As of December 2015 we had 1,867 SMART applications completed for 150 awards to be made in the 2016-2017 academic year. To date, we have a retention rate of 81% within the DoD beyond their service obligation. This program has been highly successful in attracting the best and brightest to pursue careers in DoD Research and Engineering.

The Department has a critical responsibility to the dependent children of our Soldiers, Sailors, Airmen, and Marines, but military dependents often have a uniquely transitory lifestyle which can challenge our ability to fully meet their educational needs. There are currently 1.2 million military children, with 55 percent between the grades of K-12. As stated in the Joint Explanatory Statement to Accompany the National Defense Authorization Act for Fiscal Year 2015, it is in DoD's interest to promote education programs that benefit both military children and our future national security workforce, both because we have a responsibility to support those who serve and because these students are more likely to go on to serve in national security careers, including military service. To promote STEM education among military dependents, we are partnering with the National Math and Science Initiative in military-connected schools -- building on documented success in improving students' performance in rigorous STEM coursework and associated assessments. Results have been dramatic, with improvements averaging 85 percent increase in Advanced Placement Math and Science scores within the first year of implementation, and 137 percent after three years. Benefits among underrepresented minority and female groups are even higher. In Fiscal Year 2015, we have reached an additional 36 schools with the potential of reaching over 28,000 students and teachers with approximately 9,000 being military children. In Fiscal Year 2016, we are extending our partnership to include the National Science Foundation and are extending the program to include computer science as a core component of the curriculum. An investment in our STEM pipeline ensures our Nation's technological dominance and develops the innovative brainpower our Nation needs to maintain our security and deter aggression.

Preparing for the Future

The Department's goal to sustain and advance our nation's technological superiority for the 21st Century 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 protect essential US advantages in design, development, and manufacturing capabilities that would be very difficult to reconstitute if lost replace. 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 serves 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.

Our strength is in our people. We must recruit and retain the best and brightest military and civilian scientists and engineers and harness their innovative spirits to give our military forces the warfighting edge.

Ultimately, 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 best care and the decisive technology and 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 move toward driving 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

Thank you for your support of the Department's science and technology efforts as we work to discover, design and deliver the technological capabilities our warfighters will need to shape the future.

Mr. Stephen P. Welby
Assistant Secretary of Defense for Research and Engineering

Mr. Stephen P. Welby was confirmed as the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) on December 14, 2015, and serves as the Chief Technology Officer for the Department of Defense and the principal advisor to the Secretary on all matters relating to science, technology, research and engineering. As ASD(R&E), Mr. Welby is responsible for the Department's strategies and supporting plans to develop and leverage the technologies needed to ensure continued U.S. technological superiority. He provides leadership to, and establishes policy and guidance for, the development and execution of the DoD Research and Engineering program. He oversees matters from basic science and capability prototyping to research and engineering at the Department's laboratories, promotes coordination and cooperation across the DoD and between the DoD and other federal and non-federal agencies and organizations, and ensures technical exchange with allied and friendly nations.

Mr. Welby had previously served as Deputy Assistant Secretary of Defense for Systems Engineering, and was responsible for establishing and executing engineering policy and oversight across the Department. His responsibilities included engineering design, development and manufacturing of complex military systems, and the engineering review, analysis and technical risk assessment of the Department's portfolio of major acquisition programs. He provided functional leadership to more than 40,000 technical professionals in the DoD Engineering and Production, and Quality and Manufacturing workforce. Mr. Welby also served as the Defense Standardization Executive, directing the DoD program to develop and maintain defense-critical government and commercial technical standards.

Mr. Welby has more than 28 years of government and industrial experience in technology and product development, including senior leadership positions at the Defense Advanced Research Projects Agency (DARPA). His experience includes development of leading-edge aeronautical and space systems, robotics, advanced weapons, high-performance software, and military sensor systems.

Mr. Welby holds a bachelor of science degree in chemical engineering from The Cooper Union for the Advancement of Science and Art, a master's degree in business administration from the Texas A&M University, and master's degrees in computer science and applied mathematics from The Johns Hopkins University.

Updated: December 2015

RECORD VERSION

STATEMENT BY

MS. MARY J. MILLER
DEPUTY ASSISTANT SECRETARY OF THE ARMY
FOR RESEARCH AND TECHNOLOGY

BEFORE THE

HOUSE ARMED SERVICES COMMITTEE
SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES

SECOND SESSION, 114TH CONGRESS

ON THE UNITED STATES ARMY'S SCIENCE AND TECHNOLOGY (S&T)
PROGRAM FOR FISCAL YEAR 2017

FEBRUARY 24, 2016

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COMMITTEE ON ARMED SERVICES

STATEMENT BY
MS. MARY J. MILLER
DEPUTY ASSISTANT SECRETARY OF THE ARMY
FOR RESEARCH AND TECHNOLOGY

Chairman Wilson, Ranking Member Langevin, and distinguished members of the Subcommittee, thank you for the opportunity to discuss the Army's Science and Technology (S&T) Program for fiscal year (FY) 2017. I greatly appreciate the support this committee has shown Army S&T over the years. You remain important partners in our mission to identify, develop and demonstrate technology options that inform and enable affordable capabilities for the Soldier.

The coming years will see important shifts in the strategic environment in which the U.S. Army operates. Geopolitical changes are coupled with equally profound global technological and economic changes. The United States has traditionally been able to produce the equipment and technology necessary to dominate. However, we are seeing technology evolving at an exponential rate along with an increased rate of technology proliferation, which has become much more affordable to weaponize. Our enemies' access to this advanced technology has closed the gap in our overmatch. The technological world is becoming ever flatter and more dynamic, and we are in a race with our adversaries to harness and field the best military applications of product innovation.

"We will do what it takes to build an agile, adaptive Army of the future. We need to listen and learn - first from the Army itself, from other Services, from our interagency partners, but also from the private sector, and even from our critics. Developing a lethal, professional and technically competent force requires an openness to new ideas and new ways of doing things in an increasingly complex world. We will change and adapt."

- GEN Milley, *Chief of Staff, Army*

The Army S&T Enterprise cannot predict with certainty what challenges and threats the future holds, but it can organize itself to help prepare for the future, mitigating the possibility of technical surprise and ensuring that we remain dominant in any environment. Transparency, efficiency and flexibility help us invest our limited resources where they have the greatest payoff. This framework allows us to adjust our approach in response to changing circumstances, while providing the stability needed for long-range S&T. The U.S. Army's nearly 12,000 scientists and engineers are innovative change agents committed to developing the science and technologies that provide America's Soldiers with the capabilities to overcome adversaries, both today and tomorrow. I am proud to represent them here today before you.

Strategic Environment

The United States finds itself facing a declining defense budget and challenges from new adversaries everywhere. A new generation of threats and opportunities has emerged that will continue to evolve in unprecedented ways. As our current large-scale military campaign ends, the United States faces a complex and growing array of security challenges across the globe. Future conflicts could range from hybrid contingencies[1] against proxy groups using asymmetric approaches, to a high-end conflict against a state power armed with weapons of mass destruction or technologically advanced anti-access and area-denial (A2/AD) capabilities.[2]

"Our fundamental task is like no other – it is to win in the unforgiving crucible of ground combat. We must ensure the Army remains ready as the world's premier combat force. Readiness for ground combat is – and will remain – the U.S. Army's #1 priority. Developing a lethal, professional and technically competent force requires an openness to new ideas and new ways of doing things in an increasingly complex world."

- GEN Milley, *Chief of Staff, Army*

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[1] Hybrid warfare is a military strategy that blends conventional warfare, irregular warfare and cyberwarfare often used to mask the identification of the aggressor in order to avoid attribution or retribution.

[2] 2014 Quadrennial Defense Review, March 2014, 12.

The future Army will be smaller and increasingly based in the continental United States. Yet it must remain capable of conducting the full range of operations on land, including prompt and sustained land combat as part of large, multiphase joint and multinational operations.

While the future force will become smaller and leaner, its great strength will lie in its increased agility, flexibility and ability to deploy quickly, while remaining technologically advanced. To prevent enemy overmatch, the Army must develop new capabilities while anticipating enemy efforts to emulate or disrupt those capabilities.

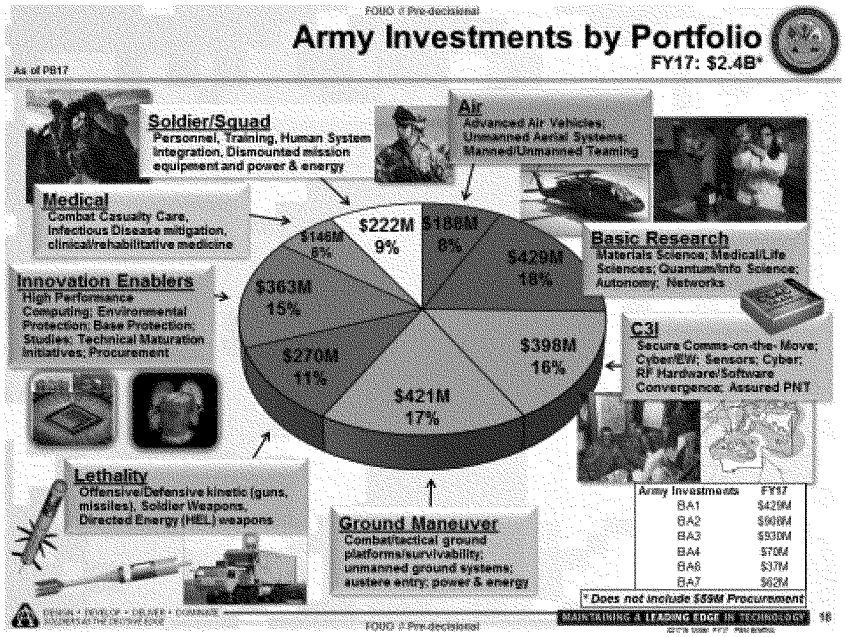
Army S&T is actively involved with the Office of the Secretary of Defense (OSD)-led Long Range Research and Development Planning Program for Ground Combat (LRRDPP-GC). Chartered in September 2015, the LRRDPP-GC is a follow-on to the original LRRDPP, which was focused on A2/AD concepts. This new study is a six-month effort tasked with identifying high-payoff enabling technology investments to provide U.S. forces with a decisive advantage in land-associated operations in the 2030 timeframe. The LRRDPP-GC is modeled after a similar effort that was conducted in the 1970s which led to the accelerated maturation of a suite of capabilities that the U.S. relies on today and leverages the LRRDPP #1 study conducted earlier this year with the focus on A2/AD. The LRRDPP-GC focuses on ground combat technologies that can be incorporated into developmental programs over the next five years and acquired and fielded in quantity within 15 years.

The Army's differential advantage over enemies derives, in part, from the integration of advanced technologies with skilled Soldiers and well-trained teams.

—The U.S. Army Operating Concept

Army S&T Portfolios

For coordination and oversight across the Army S&T Enterprise, the Office of the Deputy Assistant Secretary of the Army for Research and Technology (ODASA(R&T)), organizes the S&T budget and programs into eight S&T Portfolios. Each Portfolio is overseen by a Portfolio Director within the ODASA(R&T) who coordinates the Planning, Programming, Budgeting and Execution process inputs and other oversight actions specific to that Portfolio. The Army S&T portfolios address challenges across six Army-wide capability areas: Ground Maneuver, Soldier/Squad, Air, Command, Control, Communications and Intelligence (C3I), Lethality and Medical portfolios. There are also two S&T enabling portfolios: Innovation Enablers and Basic Research.



Army S&T Enterprise Program Funding % Breakdown by Portfolio

In Fiscal Year 2017 (FY17), the Army will maintain the 2016 President's Budget level of S&T funding and will sustain or increase resources supporting OSD areas in fundamental sciences, such as advanced materials and synthetic biology, research in the areas of human performance, robotics and autonomous systems and advancing capabilities such as defense against ballistic and cruise missile and air threats, electronic warfare and network defense.

Army S&T investment portfolios support Army modernization goals to develop and field affordable equipment in a rapidly changing technological and economic environment. The S&T Enterprise addresses this need by fostering technology invention, innovation, demonstration and maturation for the current and future fight.

Army S&T Strategic Initiatives

In past years, I have detailed to the Committee our enduring Army challenges and how they influence the S&T portfolios. Today, I would like to take the opportunity to instead describe some newer strategic initiatives that cut across our portfolios and are instrumental in helping us realize our objectives – Technology Wargaming, S&T Red Teaming, and Prototyping/Technology Maturation Initiatives (TMI).

Technology Wargaming

Technology Wargaming is a reconnaissance effort focused on scouting for S&T trends that could provide innovative capabilities for operations in the deep future. It leverages scientists and engineers, experts in military operations, and creative thinkers from academia, industry, federally funded research and development centers, and other hubs of innovation to analyze S&T trends and identify future technology concepts that are feasible and bounded by the laws of physics. Technology Wargaming is used to inform strategic conversations on technologies that could deliver leap-ahead capabilities for the future force, and how best to align resources and organizations to pursue those

opportunities. It serves as part of a broader Army effort to break down communication barriers that have hindered innovation and facilitates Army S&T's ability to capture innovative ideas from nontraditional partners.

Technology Wargaming helps provide background technical underpinning for the Training and Doctrine Command (TRADOC) annual Unified Quest (UQ) Wargame, encourages innovative thinking and strategic dialogue within the Army S&T community, and informs future capabilities/needs/concepts and the potential for innovative, cutting-edge technologies to address them.

Some of the key milestones for Technology Wargaming include scouting open source information for U.S. and foreign S&T trends. These trends are analyzed by Subject Matter Experts (SMEs) within the Army S&T and Intelligence communities and added to crowd-sourcing ideas from scientists, engineers, thought leaders and creative thinkers inside and outside the Government. These exercises contemplate how S&T may influence the world and military capabilities in the deep future, and combine results from trend scouting, SME surveys and crowd-sourcing to create a set of future technology concepts and roadmaps. These concepts represent conceivable technologies that could affect capabilities available to the U.S. Army and potential adversaries within the next 30 years.

Another example of S&T forecasting is conducted by the Army Research Laboratory (ARL). This forecasting is guided by the principle that actors in future conflict will seek to persuade in three realms: physical, the domain of activities defined in space and time by the laws of physics; informational, the domain of activities defined by thought and perception; and cultural, the domain of activities defined by the interaction of people and societies. Workshops between government, industry, and academic experts probe the potential of these areas to provide new military capabilities. Among other topics considered this past year, these workshops examined the technologies necessary to

enable expeditionary on-demand manufacturing and integrated teaming between Soldiers and intelligent systems[3].

S&T Red Teaming

A key component of the S&T strategy is broadening and deepening our ability to identify, understand and eliminate potential vulnerabilities in emerging technologies and future systems that could threaten their success upon deployment in Army operational settings. To achieve this, the S&T Red Teaming investment provides in-depth, independent assessments of emerging technologies across laboratory, table-top, and live field environments. These assessments seek to uncover potential vulnerabilities of future Army systems when employed in a system of systems context and against an evolving and responsive threat.

In FY14, building from the success of our Deployable Force Protection efforts, my office initiated an innovative program to identify, understand and eliminate potential vulnerabilities in emerging defense technologies and systems that could threaten their success upon deployment and use in Army operational settings. The core components of this program are Technology Red Teaming, which provides in-depth, laboratory-based vulnerability assessments and Adaptive Red Teaming, which seeks to uncover potential vulnerabilities of emerging technologies when employed in a systems context against an evolving and responsive threat.

S&T Red Teaming embraces a philosophy of leveraging independent and multidisciplinary perspectives across a broad range of future employment factors and scenarios to purposely introduce novel, nontraditional thinking into technology development. It seeks to extend solution design considerations in a way that avoids ingrained biases and practices that can unintentionally introduce vulnerabilities when employed. Moreover, by identifying technology vulnerabilities early in the development

[3] A collective of physical or software agents acting independently but under human supervision to conduct military relevant missions.

life cycle, the Army encourages adaptation and mitigation at times where changes can be economically accommodated with the highest likelihood of equipping Army Warfighters with operationally robust systems.

Technology Red Teaming applies state-of-the-art engineering and scientific approaches to identify and assess potential vulnerabilities in developing technologies and materials specific to system design choices, and to ascertain their potential robustness once implemented into Army systems. These efforts independently assess technologies in ways that complement, yet extend beyond typical material testing. These assessments consider current, emerging and future threats, emerging disruptive technologies, and cutting-edge materials science developments in ways that effectively address potential future scenarios and yield engineering tradeoffs that may not have been considered previously. Ultimately, Technology Red Teaming seeks to proactively identify and mitigate unforeseen risks and vulnerabilities as new technologies are adopted by the Army and promote the development of S&T products that are "threat ready."

Adaptive Red Teaming applies state-of-the-art and time-proven Red Teaming methods within a series of multidimensional, multi-organizational, in-depth activities to identify and assess potential system and/or system-of-systems vulnerabilities. While the Technology Red Teaming activities pursue within-system robustness, the Adaptive Red Team (ART) activities look to the seams of system-of-systems interaction to provide a full consideration of successful integration. The crown jewel of our ART activities is our Technical Support and Operational Analysis (TSOA) effort. TSOA exercises provide technologists and systems developers with realistic and challenging multi-day experiments to employ and assess their solutions prior to entering acquisition programs. Collaborative, non-punitive experiments take emerging systems and prototypes out of the lab and into “messy” environments, incorporating varied operational and increasingly complex scenarios against capable adversaries, using experienced warfighters and security forces that provide real-time user feedback on both design and performance. In these settings, technology solutions are examined from multiple perspectives – including systems integration, logistics, training and adaptability risks –

in order to expose potential employment vulnerabilities and identify needed improvements early on. TSOAs are conducted quarterly in a variety of different environments, from the desert to the marshlands to urban environments.

The TSOA methodology has proven to be successful and has spawned a number of successes. For example, based on TSOA assessments and feedback resulting in system improvements, SOCOM purchased over twenty five Frontier Tag, Track and Locate devices for use in low visibility operations. Additionally, the Prowl radar-based ground sensor participated in several TSOAs and used the feedback to make system improvements and fix identified vulnerabilities. As a result, it passed Army Test and Evaluation (ATEC) testing and is now part of a USSOCOM PEO-Special Reconnaissance, Surveillance, and Exploitation Program of Record.

The vulnerability assessments we are doing are also bringing interesting and useful results for technologists and system developers. For example, we have an ongoing effort to look at individual blade control (IBC) technologies that can offer substantial improvements in flight control and performance of rotorcraft systems. An in-going hypothesis for these technologies, however, is that flight control capabilities would be significantly reduced if the blades were to receive ballistic damage in a combat environment. This is seen as a major hurdle to the adoption of IBC technologies for military rotorcraft. In recent live-fire red teaming intended to better understand IBC's ballistic vulnerabilities, a rotor blade test article continued to function properly following each of three shots, with an apparent minimal reduction in control authority. While we have much more analysis to conduct in order to understand the overall feasibility of IBC technologies, this is an example of how knowledge generated under early, technical red teaming assessments are helping to reduce the risk of adopting high-payoff technologies into future platform designs.

Overall, the results of the Technology Red Teaming and Adaptive Red Teaming activities enable the Army S&T and acquisition communities to become stronger by determining early in the lifecycle how well technologies and integrated systems can

perform in hostile environments, most notably against near-peer threats and against exploitation by adaptive, adversarial forces.

Prototyping and Technology Maturation Initiatives

A number of years ago the Army entrusted my office to initiate what amounted to a pilot initiative. They established a Budget Activity 4 (Advanced Component Development and Prototypes (ACD&P)) funding line under the authorities of the DASA(R&T) with the intent to enable the Army to better transition across the often cited "Valley of Death". This pilot began with a small amount of dollars but with a large vision -- a vision that included a collaborative partnership with the acquisition and requirements community and a multi-pronged approach to improved transition: 1) to work with the Program Executive Offices (PEOs) on technology maturation for pre-Milestone (MS) A or B activities that would lead directly into a Program of Record (PoR) and 2) work with the requirements community to prototype new capabilities and provide them to operators to allow real and candid feedback. These activities help to better inform requirements for new systems, as well as drive down the risk of integrating new technologies, by demonstrating mature solutions that are technically achievable and affordable. In conducting maturation and prototyping earlier in the acquisition lifecycle, we can identify and address areas of risk before the government commits more significant levels of funding to a PoR. Ultimately, it is much more cost-effective to prove out innovative concepts and capabilities in the S&T program than it is under formal program acquisition.

The Army's Technology Maturation Initiative (TMI) is our 6.4 line, which established a strategic partnership between the S&T Enterprise and acquisition communities to enable the transition of priority technologies at reduced cost and risk. A current priority under the TMI is the set of efforts focused on driving down cost and technical risk for technologies that provide dismounted and mounted Soldiers with trusted Position, Navigation and Timing (PNT) information, while operating in conditions that impede or deny access to the Global Positioning System (GPS). The S&T Enterprise is

addressing risk in four thrust areas: (1) Pseudolites (pseudo-satellites) that augment or replace military GPS signals by developing a terrestrial/aerial based GPS-like signal, enabling signal acquisition/tracking, navigation and timing in degraded or denied environments (this transitioned at a MS A to the Assured PNT PoR in June 2015); (2) a PNT hub for vehicular applications that develops a robust system to support all PNT needs on the platform and maintain PNT capability during operations in GPS-denied environments; (3) a PNT hub for dismounted Soldiers systems that has low SWaP and can provide assured PNT signals for all Soldier equipment; and (4) Anti-Jam Antennas that enable GPS signal acquisition and tracking in degraded or denied environments. These PNT efforts leverage both traditional S&T and TMI investments, and have a direct tie into the Assured PNT PoR. By further developing these technologies to a relatively high maturity level, we are driving down the risk to the PoR, accelerating capability, and ensuring that our troops will be able to operate in a contested environment.

In FY16, we initiated a major, multi-year effort within TMI on Combat Vehicle Prototyping (CVP). The CVP Program is designed to mature technologies to address technical and integration challenges facing the ground combat fleet in the areas of mobility, survivability, lethality and vehicle architecture. CVP focuses on maturation and demonstration of combat vehicle sub-systems such as engines, transmissions, ballistic protection, blast mitigation, lethality subsystems and advanced fire controls. The goal is to mature and demonstrate, by FY19, a series of subsystems that inform current and next-generation combat vehicle designs and requirements. These activities will ensure future acquisition program requirements are informed with what is technically feasible and affordable, while driving down technical risks. Technologies developed under combat vehicle prototyping are scalable and modular to ensure applicability for current and future vehicles across the combat fleet. In FY17, we will expand the combat vehicle prototyping activities by funding the integration of these subsystems to create a full system prototype that can be used by operators to provide performance feedback and design insights before we finalize formal requirements for the Army's next combat system.

Another of our major prototyping activities is the Modular Active Protection System (MAPS). The MAPS program is developing technologies in order to increase vehicle survivability and protection against current and emerging advanced threats. Technologies developed will provide this increased protection while maintaining or reducing vehicle weight by reducing reliance on armor through the use of other means such as sensing, warning, hostile fire detection and active countermeasures.

While the S&T Enterprise has developed and demonstrated successful active protection capability in the past, each system was designed for a specific platform and threat set. The MAPS effort is a departure from previous APS efforts in that it establishes an APS Common Architecture (CA) and APS common controller (algorithms and software) applicable across all military vehicles. MAPS is developing the APS CA to have standard interfaces that enable adaptable APS solutions that can be integrated across Army vehicle platforms as required. The APS CA provides the flexibility, potential component commonality and growth capability to enable "Best of Breed" components. This helps alleviate integration and cost challenges across the military vehicle fleet. In order to test and validate MAPS and the APS CA, a soft-kill demonstrator and a hard-kill/soft-kill demonstrator will be developed and tested in FY17 and FY19, respectively. The goal of this effort is the development and demonstration of an effective APS capability and APS CA that establish and document standardized interfaces, subsystem specifications and a verified and validated APS simulation tool.

Experimentation and prototyping activities like those described above are critical to the development of successful acquisition programs. We began to see clear indicators of the value of early prototyping many years ago. The Future Tactical Truck System (FTTS) is a good example of how Army S&T seed corn enabled the Joint Lightweight Tactical Vehicle (JLTV) acquisition program. The FTTS effort started over fifteen years ago at the Tank Automotive Research Development and Engineering Center (TARDEC). TARDEC led the S&T technology development effort that demonstrated mature technologies which ultimately led to realistic and achievable requirements. The FTTS

prototyping model stressed close coordination between the technology, requirements, and acquisition communities.

While 15 years is a long time, it is important to note that the development of JLTV and its S&T predecessors occurred during a time of war, which impacted TARDEC priorities and caused us to learn several new things such as the need for vehicle underbody protection. It was during this same time that the TARDEC team worked with the Army Research Laboratory (ARL) on such major initiatives as designing and implementing Frag Kit armor in response to Operational Needs Statements (ONS) coming out of Iraq and with the Program Executive Office for Combat Support & Combat Service Support (PEO CS/CSS) on the development of the Mine-Resistant Ambush Protected (MRAP) vehicle in response to Joint Urgent Operational Needs Statement (JUONS) coming out of Afghanistan. The S&T technology development, system design, and fabrication and testing drove down the risk for the JLTV MS A decision, and compressed the Technology Development (TD) Phase "preparation" time (e.g., specs, Statement of Work, Contract Data Requirements Lists, etc.). The S&T effort also ensured that there was viable competition for the TD phase by preparing industry to be able to bid and compete. This allowed the Program of Record to conduct a competitive acquisition process and to leverage the different companies' strengths to get the best out of the program as a whole.

The Army S&T Enterprise

The Army owns a vast network of research and development facilities located across the world, with roughly 12,000 scientists and engineers that make up the heart of what we do. The Army relies on its laboratories and centers (collectively referred to as “labs”) to foster innovation; develop and demonstrate new technologies; assess competing technology options; and help transition research as they mature. A flexible and agile workforce is critical to maintaining the Army’s technological superiority now and in the future. Critical to the development of the agile workforce is the ability to recruit new employees, the ability to develop existing employees and the ability to retain these same employees. Recruiting, developing and retaining the best science and

engineering talent into the Army laboratories have become increasingly challenging due to a series of events - the pay freeze instituted in 2010; conference restrictions implemented in 2012; furloughs related to sequestration in 2013; and retirement eligibility for greater than 25 percent of the workforce. The labs have benefitted greatly from authorities provided by Congress to all Science and Technology Reinvention Laboratories (STRL) to implement pay-for-performance systems. The personnel systems they have developed give the labs the flexibility to enhance recruiting (direct hire mechanisms), development (sabbaticals and critical skills training) and retention (retention allowances) of our workforce. With two exceptions[4] (the Army Research Institute for Behavioral and Social Science (ARI) and the Space and Missile Defense Technology Center (SMDTC)), all the Army laboratories have some portion of their workforce rated under a pay-for-performance system. The flexibility available to the laboratory directors allows them to shape their workforce and remain competitive with the private sector.

In order to recruit and retain a world-class workforce, we must also be able to maintain a world-class infrastructure. As I've testified before, our laboratory infrastructure is aging, with an average approximate age of 50 years. Despite this, the S&T Enterprise manages to maximize the sustainment, restoration and modernization funding and the authorities provided by Congress for minor military construction to minimize the impact of aging infrastructure. This is not a long-term solution, however. The Army S&T Enterprise is faced with a highly competitive Army MILCON environment that is focused on investment to build out the critical shortfalls in the following Focus Areas by 2029: Energy/Utilities, Organic Industrial Base, Organizational Vehicle Maintenance, Reserve Component Readiness Facilities, Trainee Barracks and Training Support Systems. Properly maintaining world-class research facilities will be a major challenge for the Army S&T Enterprise in the years to come.

Of course, innovation does not only take place in Army labs. The Army engages industry and academia to identify potential technology solutions to priority problems and

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[4] Both ARI and SMDTC were granted authority to become STRLs in the FY15 NDAA and are assessing plans for conversion to the laboratory demonstration system.

capability challenges through stronger partnerships. One example is the Defense Innovation Marketplace, an online portal with two primary purposes: a broad, public-access communication tool used by the Army to communicate its needs directly to industry, and a portal for industry to place/announce its independent research and development (IR&D) technology efforts in a Government-only access environment that protects proprietary information. Through the Marketplace, the Army provides industry with a primary source of information about the Army's investment priorities and technology requirements, giving industry the ability to better align its IR&D projects with the Army's needs.

Another example of how we engage with industry and academia, and one that I believe has been a great success, is the Army Research Laboratory's (ARL) Open Campus. Open Campus forms a global S&T ecosystem to provide long term benefits for our national security, and lays the groundwork for joint teaming through fundamental science and technology. Collaboration partners fund their own efforts and work in research areas of mutual benefit that align with ARL's Technical Strategy. Since last year the number of agreements with academia and industry have doubled, from 60 to over 130. These agreements have leveraged over $16M from the Army's collaborative partners. The total number of open campus participants have also doubled from over 200 to beyond 500 participants collaborating on-site in ARL laboratories. The implementation of enhanced layered security practices have allowed over 54 international collaborators from 19 countries to work alongside Army researchers within the installation. Human resource best practices are being revisited to encourage around 10% ARL's workforce to take assignments at universities, with small business, and with other partners. These assignments could be anything from working with a collaborator for a month on a shared project, going to a University as a professor for a semester or two, or even supporting a small business for several years. For example, ARL scientists and engineers are embedded at the National Institutes of Health researching mechanisms to alter intercellular dynamics for traumatic brain injury protection, and at the University of Massachusetts, Amherst researching fundamental principles of novel low profile antenna concepts. The Army is establishing several research centers to focus large scale collaboration on Army challenges. The Center for

Research in Extreme Batteries has been established with the University of Maryland and the National Institute of Standards and Technology (NIST) to focus on the fundamental science for batteries with extreme properties, operating in extreme environments for defense, space and biomedical applications. This first center has already attracted the interest of hundreds of participants from DoD labs, universities, other government laboratories, and industry.

The majority of DoD Laboratories are concentrated in the eastern United States. This leaves the DoD with minimal exposure to the west coast, where many new ideas and technologies are being generated. ARL West, as an extension of the Open Campus initiative, is an effort to co-locate Army research and development personnel on the West Coast in order to gain access to SMEs, technical centers, and universities not well represented on the East Coast. ARL West draws from existing large regional talent pools and establishes areas for collaborative research in Army-relevant technology sectors. We expect increased collaboration with universities, start-ups and established companies working in simulation and training, electronics, information science, intelligent systems, and human-system interaction that will ultimately benefit the Soldier and ensure our nation's future strength and competitiveness.

ARL has established an agreement with the University of Southern California (USC) to stand up ARL West. USC will provide nearly 22,000 sq. ft. in support of up to 70 Army personnel and focus initially on research between USC's Institute for Creative Technologies (ICT) (an Army University Affiliated Research Center) and ARL. This is the first collaboration center located near Los Angeles (LA) in the so-called Silicon Beach area, which is home to more than 500 tech companies including Google, Yahoo!, YouTube, and many others. In addition, the LA area is one of the largest regions for graduating engineers in the country. Researchers are expected to arrive in early 2016 and will include locally recruited scientists, students, and representatives from other Army organizations. The ARL West campus ribbon cutting ceremony and opening are tentatively scheduled for April 2016. We are hoping that this new venue will help establish a significant link to some of the most cutting-edge, innovative companies in the world.

Conclusion

Our primary goal is to provide capabilities and materiel solutions that empower, unburden and protect our Soldiers in an environment of uncertainty and complexity. Simply put, it's providing Soldiers with the Technology to Win. As the Army S&T program continues to identify and harvest technologies suitable for transition to our force, we aim to remain ever vigilant of potential and emerging threats. We are implementing a strategic approach to modernization that includes an awareness of existing and potential capability gaps, understanding of emerging threats, knowledge and leveraging of state-of-the-art commercial, academic and government research, and understanding the competing needs for limited resources. Ultimately, our focus remains on Soldiers. Army S&T consistently seeks new "ways" to increase the Soldier's capability and ensure their technological superiority today, tomorrow and decades from now. The Army's strong support of the S&T Enterprise and its continued investment in technology ensure that the U.S. Army remains the pre-eminent force in the world. The Army S&T mission is never complete. We will continue working to ensure that our Soldiers are always equipped with the technology to win – our "ends". We owe our Soldiers no less.

"No matter where we are around the world, America's Soldiers are displaying courage, commitment and character. We are demonstrating unparalleled competence and agility. And no matter the challenge, no matter how complex the environment, or how dangerous the situation, our Soldiers fight and win."

- GEN Milley, *Chief of Staff, Army*

Ms. Mary J. Miller
Deputy Assistant Secretary of the Army
(Research and Technology)

Ms. Miller was selected for the Senior Executive Service in August of 2005. In February of 2013, she was designated as the Deputy Assistant Secretary of the Army for Research and Technology. Ms. Miller is responsible for the entirety of the Army's Research and Technology program, spanning 16 Laboratories and Research, Development and Engineering Centers, with more than 12,000 scientists and engineers and a yearly budget of just over $2 billion dedicated to empowering, unburdening and protecting Soldiers.

CAREER CHRONOLOGY:
Feb 2013 – Present: Deputy Assistant Secretary of the Army (Research and Technology
Sep 2012 – Feb 2013: Acting Deputy Assistant Secretary of the Army (Research and Technology
Dec 2010 – Sep 2012: Deputy Program Executive Officer Soldier
Aug 2005 – Dec 2010: Director for Technology, Office of the Assistant Secretary of the Army for Acquisition, Logistics and Technology, Pentagon, Washington, D.C.
Apr 2001 – Aug 2005: Deputy Director of Technology for Aviation, Missiles, Soldier and Precision Strike under the Director for Technology, OASA(ALT), Pentagon, Washington, D.C.
Oct 1992 – Apr 2001: Team Leader Nonlinear Optical Processes Team, U.S. Army Research Laboratory (ARL), Adelphi, MD
Jun 1999 – Jun 2000: Science and Technology Liaison to the Deputy Chief of Staff for Operations – Force Development (now the DCS G8-FD). Pentagon, Washington, D.C.
Mar 1990 – Oct 1992: Team Leader, Advanced Optics Team, Project Lead for the Visible/Near Infrared (VIS/NIR) Sensor Protection efforts, Night Vision & Electro-Optics Directorate, Laser Division, Ft. Belvoir, VA
Jul 1984 – Mar 1990: Electronics Engineer, Night Vision & Electro-Optics Directorate, Laser Division, Ft. Belvoir, VA

COLLEGE:
Masters of Business Administration from the University of Tennessee, Knoxville, TN.
Masters of Science in Electrical Engineering, Electro-Physics from the George Washington University, Washington, D.C.
Bachelor of Science in Electrical Engineering from the University of Washington, Seattle, WA.

AWARDS AND HONORS:
Army Research & Development Achievement Award in 1988 for her technical achievement in the "Development of Nonlinear Materials for Sensor Protection."
Four patents awarded for sensor protection designs, two additional patents pending.

CERTIFICATIONS:
Certified Level III in Program Management
Certified Level III SPRDE, Systems Engineering
Certified Level II SPRDE, Program Systems Engineering

PROFESSIONAL MEMBERSHIPS AND ASSOCIATIONS:
Association of the United States Army (AUSA), member since 2003

MAJOR PUBLICATIONS:

Ms. Miller has published more than 50 papers and has addressed over 30 major commands and international groups with technical presentations. She served as a conference committee member and co-chair for SPIE Conference on Nonlinear Optical Liquids, 1996-1998 and served as a peer-reviewer for technical papers in her area of specialty submitted to the Journal of Applied Optics, Applied Optics and Optics Letters from 1987-1999.

B.P. Ketchel, C.A. Heid, G.L. Wood, M.J. Miller, A.G. Mott, R.J. Anderson, and G.J. Salamo, "Three-Dimensional Color Holography Display," Appl. Optics, 38:6159 (1999)
G.L. Wood, A.G. Mott, and M.J. Miller, "Investigation of Tetrabenzporphyrin by the Z-scan Technique," Opt. Lett., 20:973 (1995).
G.L. Wood, W.W. Clark, III, M.J. Miller, G.J. Salamo, E.J. Sharp, R.R. Neurgaonkar, J.R. Oliver, "Photorefractive Materials" (invited) Book Chapter in Spatial Light Modulators: Materials, Devices, and Applications, ed. U. Efron, Marcel Dekker, New York NY, p.161-215 (1994).
E.J. Sharp, W.W. Clark, III, M.J. Miller, G.L. Wood, B. Monson, G.J. Salamo, R.R. Neurgaonkar, "Double Phase Conjugation in Tungsten Bronze Crystals," Appl. Opt. 29:743 (1990).
B. Monson, G.J. Salamo, A.G. Mott, M.J. Miller, E.J. Sharp, W.W. Clark, III, R.R. Neurgaonkar, "Self-Pumped Phase Conjugation with Nanosecond Pulses in Strontium Barium Niobate," Opt. Lett., 15:12 (1990).
W.W. Clark, III, G.L. Wood, M.J. Miller, E.J. Sharp, G.J. Salamo, B. Monson, R.R. Neurgaonkar, "Enhanced Photorefractive Beam Fanning Due to Internal and External Electric Fields," Appl. Opt., 29:1249 (1990).

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HOUSE ARMED SERVICES COMMITTEE
EMERGING THREATS AND CAPABILITIES SUBCOMMITTEE

STATEMENT OF
REAR ADMIRAL MATHIAS W. WINTER, UNITED STATES NAVY
CHIEF OF NAVAL RESEARCH

BEFORE THE
EMERGING THREATS AND CAPABILITIES SUBCOMMITTEE
OF THE
HOUSE ARMED SERVICES COMMITTEE
ON
THE FISCAL YEAR 2017 BUDGET REQUEST

FEBRUARY 24, 2016

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HOUSE ARMED SERVICES COMMITTEE
INTELLIGENCE, EMERGING THREATS AND CAPABILITIES SUBCOMMITTEE

Introduction

Thank you for the opportunity to talk to you today about the Department of the Navy (DoN) Science and Technology (S&T) Strategy and discuss how the President's FY 2017 Budget for S&T investments supports our Sailors and Marines. The FY 2017 Budget requests $2 billion for Naval S&T. At almost 1.4 percent of the entire DoN Budget, I view S&T as the venture capital of the Navy and Marine Corps. In building a future Fleet and Force to achieve U.S. national security objectives, we balance S&T resources between a range of initiatives to support near-term advances in established operational areas – and to sustain long-term research that will prove disruptive to traditional operational concepts.

Naval Science and Technology Strategy

The Secretary of the Navy has renewed the call for innovation, recognizing its vital role in sustaining our warfighters' decisive edge. While innovation of all types and at all levels is needed, the kind of innovation that wins wars is technology-based. As the Office of Naval Research (ONR) celebrates its 70th anniversary in 2016, the Navy continues to leverage its phenomenal track record in maintaining a decisive capability advantage and the Naval Science & Technology Strategy guides these efforts. The strategy drives ongoing research and provides the foundation for how we invest the DoN's S&T budget. Our strategy is simple*: to discover, develop and deliver decisive naval capabilities, near to long term, by investing in a balanced portfolio of breakthrough scientific research, innovative technology and talented people.*

The Naval S&T Strategy outlines our investment portfolio and identifies nine S&T research focus areas: 1) Assure Access to the Maritime Battlespace, 2) Autonomy and Unmanned Systems, 3) Electromagnetic Maneuver Warfare, 4) Expeditionary and Irregular Warfare, 5) Information Dominance – Cyber, 6) Platform Design and Survivability, 7) Power and Energy, 8) Power Projection and Integrated Defense, and 9) Warfighter Performance. The Naval S&T Strategy charts our course as we navigate between existing systems and concepts of operations toward a warfighting capability to counter predicted and emerging threats in an increasingly complex, uncertain future. Starting with evolution of current systems through incremental improvement and spiral development of known technology, we move toward yet-to-be-

discovered, disruptive, game-changing technologies. The Naval S&T Strategy aligns S&T investments with Naval missions and future capability needs by targeting knowledge gaps to develop new technologies that will address warfighting capability needs.

Executing the Strategy

Naval S&T investment portfolio falls into four broad components – Discovery and Invention (D&I), Leap Ahead Innovations (Innovative Naval Prototypes/INPs), Technology Maturation (Future Naval Capabilities/FNCs), and a Quick Reaction S&T (QRST) capability to respond to emerging requirements.

Discovery and Invention

New technologies emerge from basic research. ONR's Discovery and Invention (D&I) includes basic research (6.1) and early applied research (6.2). D&I develops fundamental knowledge, provides a basis for future Navy/Marine Corps systems, and sustains our Scientist/Engineer workforce. D&I enables future capabilities, with the majority of D&I investments conducted by academic and non-profit performers. The ONR Naval Research Laboratory conducts the majority of the DoN's basic research effort across all nine focus areas. D&I is peer reviewed by outside experts and overseen by ONR program officers and senior leadership. Investment decisions are guided by need, risk, impact, significance, originality, principal investigator, and budget resources.

ONR's University Research Initiative (URI) includes the Multidisciplinary University Research Initiative (MURI), the Defense University Research Implementation Program (DURIP), and the Presidential Early Career Award for Scientist and Engineers (PECASE). MURI supports teams of researchers investigating topics that involve multiple technical disciplines. DURIP provides grants for the purchase of instrumentation necessary to perform research essential to the Navy. PECASE recognizes achievements of young scientists/engineers and encourages them to explore professions in academia and Naval laboratories. The Basic Research Challenge funds promising research not addressed by ONR's core program, while the Applied Research Challenge rewards the technical community for specific, measurable progress in new applied research. The Young

Investigator Program supports scientists/engineers with exceptional promise for Naval research. Research opportunities for undergraduate and grad students, fellows, and future faculty members are provided by the Naval Research Enterprise Internship Program (NREIP), where participants work at Naval laboratories and warfare centers. The In-House Laboratory Independent Research (ILIR) and Independent Applied Research (IAR) programs sponsor critical research and further the education of scientists and engineers at warfare centers. ONR also brings Historically Black Colleges and Universities and Minority Institutions (HBCU/MI) together with Naval laboratories and warfare centers to give students hands-on experience in Naval research.

Leap Ahead Innovations (Innovative Naval Prototypes)

ONR's Leap Ahead Innovations portfolio defines the future of naval warfighting. Leap-ahead technology initiatives demonstrate decisive new naval capabilities. Innovative Naval Prototypes (INP) are high-risk/high-payoff disruptive departures from established capabilities and operational concepts that can dramatically change how Naval forces fight, while reducing acquisition risk. The goal is to prove concepts and mature technology in 4-7 years, allowing informed decisions about risk reduction and transition to acquisition programs.

Some INP examples include the Large Displacement UUV technologies deliver game-changing capabilities to naval warfighters. Scientific leadership in autonomy and unmanned systems enabled LDUUV, which complements existing undersea capabilities and platforms. The Autonomous Aerial Cargo/Utility System (AACUS) is developing autonomous capabilities for rapid, affordable rotorcraft supply in permissive, hostile and GPS-denied settings. Electromagnetic Railgun (EMRG) is a revolutionary advancement in naval gun technology, and developmental success has enabled steady progress toward a demonstration. If realized, the capability offered by a multi-mission railgun will provide long-range land-attack, air defense, and anti-surface warfare against ships and small boats.

Technology Maturation (Future Naval Capabilities)

Technology Maturation provides vetted solutions to naval technology requirements and capability needs. It delivers critical component technologies to naval acquisition programs and

many technology transition initiatives are focused on improving affordability. This is the critical component of our transition strategy. It consists of the Future Naval Capabilities (FNC) program, USMC Advanced Technology Development (6.3) funds, Low Observable/Counter Low Observable funds, and Manufacturing Technology (ManTech).

FNCs are near-term (2-4 year), requirements-driven, delivery-oriented projects that deliver mature technologies to acquisition sponsors for incorporation into new or upgraded systems. FNCs use a collaborative process involving requirements, research, acquisition, and Fleet/Force communities to align this part of the S&T portfolio with Naval Capability Gaps identified by the Office of the Chief of Naval Operations (OPNAV) and the Marine Corps Combat Development Command (MCCDC). A gap is any capability required to achieve Naval objectives that are not achievable with current platforms, weapon systems, doctrine, organizational structure, training, materials, leadership, personnel or facilities and requires S&T investment to address. FNCs are based on D&I investments where technology can mature from Technology Readiness Level (TRL) 3 to TRL 6 in 3-5 years. As FNC products transition to Advanced Component Development and Prototypes and Engineering and Manufacturing Development, responsibility for development shifts from ONR to acquisition commands.

Quick Reaction S&T (QRS&T)

QRS&T delivers innovative solutions from ideas submitted by Sailors and Marines via the TechSolutions website. It is responsive to urgent technology needs that solve problems for warfighters, and rapid turnaround delivers a working prototype in less than 2 years. TechSolutions uses quick prototyping to meet specific requirements, with each project structured around definable metrics, and appropriate acquisition/test systems by integrated product teams. While neither a substitute for the acquisition process, nor a replacement for systems commands, TechSolutions prototypes deliver solutions to address immediate needs that can be easily transitioned to the Fleet/Force.

Expeditionary Maneuver Warfare and Combating Terrorism

In this evolving and complex world, the Marine Corps will remain the Nation's Crisis Response Force capable of operating in a forward posture in a joint/coalition environment. The Marine Corps serves as a maritime-based expeditionary force that operates across the range of military operations in a five domain battlespace (sea, air, land, cyber, and space). Projecting power from a variety of naval platforms and land bases, this highly trained and educated force will operate the most modern and technologically advanced equipment.

ONR's science and technology contribution to the Marine Corps mission is executed through the DoN's Expeditionary Maneuver Warfare and Combating Terrorism S&T portfolio. While focused on science and technology to enable new capabilities for the Marine Corps, this S&T portfolio also supports naval special warfare and the Navy Expeditionary Combatant Command. The S&T portfolio provides new technology options to enable capabilities across the areas of Human Performance Training and Education (HPT&E), force protection, logistics, C4 (Command, Control, Communications, and Computers), fires, maneuver, and ISR.

To enable greater performance of our force we demonstrated and delivered to the Marine Corps the Augmented Immersive Team Trainer (AITT), an augmented reality training system that displays virtual indirect fire effects onto actual terrain. We anticipate continued development of augmented reality capabilities ultimately moving from a training perspective into a tactical use which opens the door for different types of scientific advancement and opportunities - e.g., Continuous and Dynamic Geo-Landmark Matching, visualization research, augmented reality metrics and measurement.

The investments we make in intelligence, surveillance and reconnaissance (ISR) have advanced natural language processing and computer vision. These advances enable automated production of increasingly complex ISR products with common semantic representation of different types of data and information. The technology enables intelligence template products to refresh automatically and autonomously, potentially saving many hours of intelligence staff time. This gives Marines more time for deeper analysis and enhanced decision making and increases battlespace tempo that had been limited by the slow intelligence cycle. ISR efforts will continue

the development of deep learning methods to process information. This work has the potential of making big data operationally useful with the construction of signatures that will capture how entities interact with the world and describe relevant behavior and/or activity of those entities.

We have an active program that advances the state of Marine Corps munitions technology. The Enhanced Expeditionary Engagement Capability (E3C) project is an example of a collection of technology advancements that will yield an affordable, precision, guided, extended range, dual-mode GPS and Semi-active Laser (SAL), 81mm mortar munition (Advanced Capability Extended Range Mortar, ACERM). This advanced mortar was designed from the ground up to push the art of the possible with the goal of increased range and increased accuracy. Moving forward we will continue the pursuit of science and technology advances in wide field-of-view visible and infrared frequency band cameras, video analytics implemented on embedded processing, a semi-autonomous system interface, self-correcting fire control, and wireless communications. Advances in these areas will enable the development of weapon system autonomy for application to unmanned ground systems.

Integrated into the Naval and Joint Force with a reinvigoration of maneuver warfare, the Marine Corps will require continued technical approaches to enable high speed mobility from the sea to objective ashore. ONR's S&T continues research in hydrodynamics, propulsion, light-weight materials and human factors to enable maneuver from multiple options for entry. High water speed, reduced signature, enhanced range, and capacity all contribute to flexibility and advancing surface maneuver options, protecting landing forces, reducing risk to shipping and improving combat power build up ashore.

Through our logistics efforts we continue to research areas that reduce maintenance and improve the operations of our ground vehicles. To reduce maintenance associated with corrosion, we supported the advancement of new isocyanate-free polysiloxane-based coatings. Significant progress has been made enhancing the performance of highly hydrophobic, low-gloss, color retaining, flexible, weather resistant, isocyanate-free topcoats that resist chemical agent simulants. The last line of defense in the war on corrosion is the system's topcoat.

ONR continues to identify key S&T opportunities in academia and industry that address unique aspects of information operations, electronic warfare and cyber operations. . Marines working at the "tactical edge" face challenges that require different S&T approaches to provide the small unit, distributed, expeditionary warfighter the information they need when and wherever they need it. Our current and future S&T efforts focus on tactical self-healing networking and the ability to manage a secure mobile network with little supporting infrastructure. We support S&T to develop and apply metrics that provide the most resilient and stable network structure, as well as methods of multilayer device security. We also support technology to provide radio architectures that can quickly change between waveforms, and simultaneously transmit and receive more than one waveform.

We are pursuing science and technology that enhance our warfighting capabilities in unmanned aerial systems (UAS) and robotics, artificial intelligence and autonomous technologies that will ultimately provide tactical and operational advantage. Low-Cost UAV Swarming Technology (LOCUST) is an ONR project using the Coyote, a small expendable UAS deployed from an A-size sonobuoy tube or Common Launch Tube (CLT) that performs Intelligence, Surveillance and Reconnaissance (ISR) missions. In order to better understand and define autonomy, ONR is conducting basic research in robotic interaction/human factors; machine reasoning, learning and intelligence; scene/image understanding; bio-robotics; cognitive science, and neuroscience. These fundamentals are the keys to teaching collaboration and teaming among autonomous systems and between human and unmanned systems.

With the accelerated pace of technology development our expeditionary maneuver warfare S&T has to support training events that allow the force to test, fail, and learn. The partnership of S&T with experimentation is a crucial aspect of moving the S&T forward. In these efforts, we work directly with the Futures Directorate and the Marine Corps Warfighting Laboratory (MCWL) at Quantico, whose mission is to use war-games, experimentation, and technology assessment to validate a concept's viability – as well as identify opportunities for future force development.

Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR)

Cyber, space, and spectrum are becoming increasingly contested domains with the proliferation of anti-access, area-denial (A2/AD) capabilities among potential adversaries. We have a requirement to project power despite A2/AD challenges and to maintain maritime superiority in a highly informationalized environment. To achieve that, we are investing in S&T to provide resilient cyber operations, robust communications and networking, rapid accurate decision making, and assured electromagnetic spectrum access for battle space awareness, threat assessment, and agile spectrum maneuver.

In partnership with the Naval Research and Development Establishment (NR&DE) and other Services, ONR developed Naval Tactical Cloud (NTC) to provide the underlying information infrastructure and big data analytics that operate on tactical radio frequency networks to improve warfighting effectiveness while operating inside adversary kill chains. We will transition technologies developed by NTC to the relevant Navy programs, including the Consolidated Afloat Networks and Enterprise Services (CANES), the Agile Core Services (ACS), and the Distributed Common Ground System-Navy (DCGS-N). ONR developed the Dynamic Tactical Communications Network (DTCN) – a GOTS router – that provides enhanced security and priority-aligned routing capabilities for Command and Control (C2) thinline and plans to demonstrate the capabilities of DTCN at Trident Warrior 2016 exercise.

Understanding cyber vulnerabilities in our networks, platforms, computing and information systems, and data is essential to develop technologies that will enable total platform cyber protection for mission assurance. To this end, ONR is investing in S&T foundations and tools for resilient cyber components and systems, including hull, infrastructure, mechanical and electrical systems cyber security; trusted network, data, and computing platforms; and computer network defense. ONR developed Byzantine Fault Tolerance++ (BFT++) to provide cyber-attack fault tolerance of real-time control systems by employing a combination of artificial diversity across the controllers and a known good state recovery mechanism.

The Naval Enterprise is also developing a framework for Electromagnetic Maneuver Warfare (EMW) that will make spectrum an integral part of a strategy to deter, fight and win against near peer adversaries. This framework will bring together multiple functional elements in the domain of electromagnetics: awareness, agility, reasoning and control. This will enable the warfighter to understand, utilize, shape, maneuver, attack and defend the electromagnetic spectrum. ONR is developing S&T building blocks to support the EMW vision, which requires a holistic, coordinated approach for sensing, communications, electronic warfare, information warfare, as well as integration of kinetic and non-kinetic payloads. We developed a multi-platform adaptive sensing technology that networks multiple RF sensors to enhance search sensitivity, electronic protection, and spectral efficiency. ONR will transition the technology to relevant Navy programs of record, including F/A-18 and DDG Flight III.

Ocean Battlespace Sensing

Naval forces must be able to adapt to ocean, air, littoral and riverine environments. Changes in geopolitics, focus on strategic locations, and new detection technologies create an emerging need for more accurate, long range forecasts for DoD and Naval operations. Our basic and applied experimentation to characterize ocean, atmosphere, and arctic processes are building the foundation for the next generation of environmental prediction deployed by Commander, Navy Meteorology and Oceanography Command (CNMOC). ONR's environmental studies are conducted worldwide with international partners to gain specific knowledge of processes in various regions. Currently joint efforts are being conducted with Vietnam, India, Sri Lanka, and Singapore. Ongoing work in the Canadian Basin of the Arctic is studying ocean acoustic propagation and the effects of open water during summer months. S&T will improve understanding of surface wind impact on upper ocean dynamics and energy fluxes across ocean boundary layers and enhance our ability to forecast operational conditions. The payoff is safe and efficient Naval operations in maritime environments through improved immediate, seasonal, and long range forecasts. ONR's research is field-oriented, using oceanographic ships, aircraft, and autonomous air and undersea vehicles – including Navy-owned Research Vessels that ONR schedules and supports in partnership with the National Science Foundation (NSF) as part of the community consortium University National Oceanographic Laboratory System (UNOLS).

Contributing to our ability to understand and prevail in ocean environments, Navy operates several classes of Unmanned Underwater Vehicles (UUVs). ONR has invested in developing UUVs and autonomy for these systems for several decades, with successful transitions to the acquisition community and Fleet in the areas of Naval Special Warfare, Mine Countermeasures, Explosive Ordnance Disposal, Intelligence, Surveillance and Reconnaissance (ISR), Anti-Submarine Warfare (ASW), and Oceanography. These systems generally fall into three classes: Man-portable, Lightweight, and Large Displacement with corresponding displacement and endurance. The ONR Innovative Naval Prototype Large Displacement UUV (LDUUV INP)ill design and build five LDUUVs: two preliminary designs, two pier-to-pier vehicles, and one submarine compatible vehicle.

The program is developing energy, autonomy and core systems to operate in a complex ocean environment near harbors, shorelines, and other high traffic locations. Goals include doubling air-independent UUV energy density, using open architecture to lower cost, and enabling pier to pier autonomy in over-the-horizon operations. Achieving these goals will reduce platform vulnerability and extend the Navy's reach into denied areas. ONR is developing a long endurance, fuel cell-based power plant to be incorporated into LDUUV prototypes. A long endurance mission demonstration is scheduled in FY 2016.

As Naval S&T has succeeded in developing new capabilities, it has also created successful businesses which arose from academic institutions such as Hydroid, Inc. from Woods Hole Oceanographic Institution and BlueFin Robotics from MIT. Small Business Innovation Research (SBIR) efforts helped nurture these businesses which were bought by larger corporations - - Hydroid was acquired by Kongsberg Marine and BlueFin Robotics was acquired by Battelle. As a result, there is a mature, competitive private sector industrial base for design, development, and maintenance of UUVs and associated sensors and payloads. The exception to this is ONR's technical risk reduction in endurance and autonomy, where there is no analogous commercial need. Our Discovery and Invention, INP and other mission autonomy Future Naval Capability programs in MCM and ASW are providing the research into these critical topics.

Sea Warfare and Weapons

ONR's major focus in Sea Warfare and Weapons is to improve surface and undersea platform, and undersea weapon performance. S&T investments provide options for advanced power and electrical systems and components, and survivable, agile, mobile, sustainable, manned and unmanned, surface and sub-surface sea platforms, and undersea weapons.

Our Electric Ship Research and Development Consortium enlists academic institutions to collaborate with industry and the Naval Warfare Centers to develop electric power architectures and technologies to support high power sensors and weapons, including directed energy weapons. As part of a Department of Defense sponsored joint service initiative, ONR successfully demonstrated a Hybrid Energy Storage Module (HESM) that will lead to systems that enable electric weapons and sensor systems on legacy and next generation naval vessels. Leveraging other government work to maximize the government's return on investment, ONR coordinated this project with the Department of Energy's Advanced Research Projects Agency (ARPA-E) Advanced Management and Protection of Energy-storage Devices program.

ONR's autonomous sea surface vehicle and undersea vehicle S&T includes development of autonomous unmanned sea surface vehicles (USVs) and long-endurance, air-independent power systems for unmanned undersea vehicles (UUVs). We conducted successful tests of USVs demonstrating autonomous navigation capabilities, and multiple autonomous USVs operating jointly toward a common purpose. ONR recently conducted a successful test of a hydrogen powered fuel cell, adapted from an automotive application, in a UUV.

A key enabler of these capabilities is investment in naval materials. Investments focus on performance and affordability of materials for lightweight structures, corrosion and biofouling mitigation, maintenance cost-reduction, undersea acoustic sensors, and energy/power-dense electrical energy conversion and storage. These efforts explore and apply fundamental materials physics to discover and develop materials meeting warfighting platform demands – such as

investment in Integrated Computational Materials Engineering (ICME), a key element of the Lightweight and Modern Metals Manufacturing Initiative.

Warfighter Performance

People are the critical element in complex systems. They provide the ingenuity, collaboration, and determination necessary for operational effectiveness and resilience. Warfighter Performance S&T addresses a broad range of research questions and technology transitions that support Sailors and Marines afloat and ashore. These research areas include manpower, personnel, training and design approaches to enhance performance while reducing costs.

Advances in behavioral sciences, medical technologies, and modeling and simulation techniques are enabling new approaches to mission-critical questions such as: How do we train effectively, efficiently reducing the time and cost of pre-deployment training? How do we design intuitive systems that are easy to use, reducing the requirement for on-the-job training? How do we support decision making in distributed teams of people and autonomous agents? How do we mitigate the risks of putting our warfighters in harm's way, keeping them healthy and ready to fight?

Manpower and personnel simulations can help us design crew complements for new ships across a broad range of missions. Artificially intelligent tutoring systems can help new recruits learn basic skills, while adaptive simulation-based training systems tailor training to the needs of individual Sailors and Marines. Immersive and augmented reality displays provide experiential learning opportunities using simulation to train as we fight. Automated performance assessment techniques enable instructors to evaluate readiness at the individual and team level and to focus their efforts efficiently and effectively on the knowledge and skills gaps of the individual warfighters where it's needed. In FY15/16 the Mission Planning Application (MPA) tool developed through the Office of Naval Research Capable Manpower Future Naval Capability program transitioned to the submarine fleet with installation on 10 SSBN's and two shore trainers as part of combat system upgrades.

Intuitive, decision-centric, and user-friendly interfaces and decision support displays can reduce training requirements and associated costs while enabling more effective operational capability. Human-centered design enhances tactical, operational, and strategic decision making and planning. A deeper understanding of human intelligence, communication, and collaboration will enable better team performance and, ultimately, support peer-to-peer collaboration between human and artificially intelligent machines. Models of human social and cultural behavior will help defeat our adversaries and set the stage for more effective humanitarian assistance and disaster relief.

Synthetic biology and medical technologies are needed to mitigate warfighter risk at sea, in the air, and in austere isolated environments. In FY15, ONR demonstrated reduced noise propagation on a CVN during flight operations and noise reduction in diver helmets, a major source of noise-induced hearing loss in Navy divers. ONR synthetic biology MURIs demonstrated programmable, micro-bio-robots for environmental sensing and computer-aided design capabilities for genetic programming. The Food & Drug Administration selected ONR to provide expertise in the use of closed-loop medical monitoring and therapeutic interventions that will facilitate the use of automated care during sea-based casualty evacuation.

Naval Air Warfare and Weapons

The goal of Naval Air Warfare and Weapons research is to broadly advance the fundamental understanding of the science and technology related to air vehicles and weapons systems for future naval systems and to demonstrate technology for air platforms, missiles, and directed energy weapons in relevant environments. We invest in science and technology for improving and maintaining current aircraft, such as the FA-18 E/F/G, as well as longer term research that will enable greatly enhanced, next-generation air dominance (NGAD) systems. Many of the longer-term, basic research projects are funded at a large number of universities around the country and support fundamental advancements in science as well as supporting workforce development in Aerospace Engineering and related fields. This is critical to ensuring that engineers, particularly those with advanced degrees, are available for the defense industry and DoD laboratories to design and build next generation aircraft and weapons. We also develop,

demonstrate, and transition technologies to increase the speed, range, accuracy, and lethality of Naval weapon systems to enable rapid, precise, assured defeat of land, sea and air targets.

Naval Air Warfare and Weapons research supports the critical National Naval Responsibility (NNR) for Sea Based Aviation. ONR identifies these NNRs as S&T disciplines that are both critical for the Navy and in which other organizations will not provide sufficient investment. While other services and the commercial market invest in aircraft technology, only ONR deals with the unique S&T challenges of Sea Based Aviation. Examples of topics that are funded in the sea-based aviation NNR are materials and structures that can withstand the ultra-demanding marine environment, aircraft technology for ship launch and recovery of fixed and rotary wing aircraft, and propulsion systems that are ultra-compact and responsive to meet demands of wave off and bolter if landings are aborted, while concurrently being ultra-fuel efficient to allow for maximum range. Along with these NNR areas, there is significant investment in energetic materials, single and multiple autonomous vehicle operations, as well as directed energy and counter directed energy systems.

Last year the Solid State Laser Quick Reaction Capability (SSL-QRC) was fielded as a science and technology demonstration aboard the USS PONCE. It was successfully demonstrated as an effective weapon system and was subsequently transitioned to the fleet in the Central Command area of responsibility and is now an operational system. ONR is building on this demonstrated capability with a program to improve component and system performance for directed energy weapons called Solid State Laser - Technology Maturation (SSL-TM). The prime contractor will develop a laser weapon with a beam director system to defend against small boats, unmanned aerial vehicles, and other targets. The Naval Surface Warfare Center, Dahlgren Division will serve as the lead system integrator. The SSL-TM Program is developing a higher powered laser with enhanced capabilities that is planned to be installed and tested at sea in FY18. Technology development efforts will address improvements to laser beam quality, beam director architecture, as well as ship and combat system integration to support extended shipboard demonstrations in the maritime environment.

ONR is developing technology for electromagnetic (EM) railguns, hypervelocity guided projectiles, and the power and cooling systems to integrate these on surface combatants. The railgun is a high-power, kinetic energy weapon capable of launching precision guided hypervelocity projectiles using electricity instead of chemical propellants. Magnetic fields created by high electrical currents accelerate a sliding metal conductor, or armature, between two rails to launch projectiles to velocities greater than Mach 6 at muzzle exit. With its increased velocity and extended range, the EM Railgun will give Sailors a new capability, allowing them to conduct precise naval surface fire support or land strikes; ship defense; and surface warfare to deter enemy vessels. EM Railgun is a true warfighter game changer. Wide-area coverage, exceptionally quick response and very deep magazines will extend the reach and lethality of ships armed with this technology. The Navy partnered with the Office of the Secretary of Defense Strategic Capabilities Office (SCO) to develop closed-loop fire control command guidance for the projectile that will expand the range of future missions for the railgun and HVP.

The Tactically Exploited Reconnaissance Node (TERN) program is a joint ONR-DARPA project to demonstrate technologies enabling unmanned air vehicles to sustain operations at long range from small deck combatants such as the LCS and DDG-51. TERN is intended to improve aviation capabilities from smaller ships substantially beyond the current state-of-the-art. If successful, TERN will provide the flexibility to provide air operations support off existing ships without extensive ship modifications, and would provide the flexibility to carry interchangeable mission packages for both overland and maritime missions. It would be able to operate from multiple ship types and in elevated sea states.

The Autonomous Aerial Cargo/Utility System (AACUS) Program is intended to demonstrate a platform independent autonomous system for landing aircraft without the need for a trained pilot for its operation. Given the approximate location of the desired landing, the system will identify the location for landing by itself and will avoid potential obstacles, such as trees and power lines.

Science, Technology, Engineering and Mathematics (STEM)

A world-class, diverse science, technology, engineering and mathematics (STEM) workforce enables the Department of the Navy to maintain technological superiority across our missions

and to protect our Sailors and Marines at home and abroad. In order to cultivate a talented and well-trained workforce for the Navy and Marine Corps, the Navy has a rich history of providing educational opportunities for students of all ages. These opportunities begin with naval-relevant outreach programs at the pre-kindergarten through high school grade levels, continue through internships and other programs at undergraduate and graduate schools, support student advancement into post-doctoral work and continue through all stages of professional development.

We aim to inspire, engage and educate the next generation of scientists and engineers, and to attract, employ, develop and retain our diverse technical workforce through collaboration across the Navy, the federal government and the broad STEM community. There is no more valuable investment we can make in Naval S&T than in the minds of our workforce, investments that result in greater productivity and innovation throughout Navy laboratories, warfare centers, and in the academic and private sector.

Naval Research Laboratory (NRL)

The Naval Research Laboratory (NRL) is the Navy and Marine Corps Corporate Laboratory and reports directly to CNR/ONR. Sponsored by ONR, the NRL base research program develops S&T to meet needs identified in the Naval S&T Strategic Plan. Research at NRL is the foundation that can focus on a broad spectrum of scientific areas to advance scientific understanding for DoN, and develops technology from concept to operation when high-priority, short-term needs arise. NRL is the lead Navy lab for space systems, firefighting, tactical electronic warfare, advanced electronics and artificial intelligence. As the Navy's in-house laboratory, NRL sustains skills and innovation in a world-class workforce. Among our great challenges is the need to modernize aging NRL infrastructure so it can continue to meet the emerging needs of our future Naval forces. This is especially important as the pace of S&T advancement accelerates rapidly across the rest of the world, and near peer competitors begin to arise, challenging our Naval superiority.

ONR Global

ONR Global employs a cadre of technical experts who facilitate international research collaboration, maintain global technology awareness, and provide S&T advice and support to operational fleet/forces. ONR recognizes that R&D spending and technical innovation outside the United States are accelerating and works to improve technology outreach through global partners who assist in our pursuit of innovation and technological superiority. Investment in cooperative research can provide better products for our warfighters at reduced cost. ONR offices in London, Prague, Santiago, Sao Paulo, Singapore, and Tokyo coordinate activities with the other services and Assistant Secretary of Defense (Research and Engineering) in the host country and spanning over 55 countries. We search for emerging S&T to meet current needs, as well as requirements for future capabilities. ONR Global establishes contacts with international S&T leaders, giving us new perspectives and helping identify trends and threats. It enables us to recruit foreign scientists and engineers in partnerships that benefit the U.S. and allies. ONR Global Science Advisors relay Fleet/Force needs to the Naval Research Enterprise (Navy labs, warfare centers, affiliated universities) to facilitate development of solutions to transition back to the Fleet/Force. Science Advisors are Naval engineers who coordinate experimentation, develop prototypes, explore transition options, and collaborate with the Fleet/Force to shape S&T investments. ONR Global Science Advisers support demonstrations of ONR technologies UAVs for tactical ISR from various platforms and prototype laser weapon systems. We continue to see increasing demand for ONR Global activities to keep pace with global technology developments and Navy requirements for innovation.

Small Business Innovation Research

We must increase the return on investment in Small Business Innovation Research (SBIR). ONR's SBIR program has had success helping small businesses make progress in technology development, but we must do a better job of helping small businesses transition from S&T and development to production. Small businesses remain one of Navy's most productive sources of innovation. Active oversight and management of SBIR goals, utilizing marketing, metrics, and improved communications, will ensure that Navy is more aware of small business capabilities – and that small businesses are more aware of Navy requirements. We need to utilize small businesses to the maximum extent possible, and are already doing so in areas as diverse as

development and construction of combat ships and landing vessels, design and manufacture of airframe structural components, marine charter transportation, and non-nuclear ship repair. Small businesses have repeatedly proven their ability to provide lean, agile and innovative solutions to warfighter needs.

70th Anniversary

ONR has been delivering technology innovations to naval forces for 70 years. Established by Public Law 79-588 in August 1946, ONR was our nation's first federal research agency. Although WWII had ended, Congress, the Navy and academia realized the importance of science and technology to meeting the challenges of modern warfare. The technological edge provided by innovations such as radar and the proximity fuze proved key to our warfighters to defeat our adversaries. The Navy had a strong research enterprise in the Naval Research Laboratory and Naval Warfare Centers, but saw the value in expanding the enterprise to academia and industry. Public and private universities, faculty and graduates students could propose naval relevant research. This ongoing Navy investment in civilian research would maintain and build the academic science base and provide a pipeline of science and technology for the future.

By discovering and working with top minds—both here at home and around the world—fostering scientific research to support naval power remains as vital today as it was 70 years ago.

Conclusion

ONR's vision is to "never put a Sailor or Marine in fair fight!" Naval S&T investments represent careful stewardship of taxpayer dollars that lead turns our DoD's toughest challenges that delivers decisive capabilities. The FY 2017 President's Budget request will enable us to move toward enhanced naval capabilities, more effective partnership between research and acquisition, and strengthen partnerships with the Army, Air Force, DARPA and other DoD research organizations – as well as performers outside the Naval R&D system. Thank you for your support of naval science and technology as we discover, develop and deliver decisive naval capabilities for our warfighters.

Rear Admiral Mathias W. Winter
Chief of Naval Research/Director, Innovation Technology Requirements, and Test & Evaluation (N84)

Rear Adm. Mathias Winter, a 1984 graduate of the University of Notre Dame with a Bachelor of Science in Mechanical Engineering, received his commission through the Naval Reserve Officers Training Corps and was designated a naval flight officer in 1985.

Winter served operational tours as an A-6E Intruder Bombardier/Navigator with Attack Squadrons 42, 85 and 34 making multiple deployments aboard aircraft carriers USS Saratoga (CV 60), USS America (CV 66), USS Dwight D. Eisenhower (CVN 69) and USS George Washington (CVN 73).

Winter's acquisition tours include assistant deputy program manager (DPM) for the Joint Standoff Weapon System; executive assistant to the Joint Strike Fighter (JSF) program director; chief engineer for JSF Integrated Flight and Propulsion Control; DPM for the Tactical Tomahawk All-Up-Round development program; chief of staff to the Program Executive Officer (PEO) for Tactical Aircraft Programs; and his major acquisition command tour as the Precision Strike Weapons (PMA-201) program manager.

Winter has served flag tours as the commander, Naval Air Warfare Center Weapons Division, China Lake/Point Mugu, California, assistant commander for Test and Evaluation, Naval Air Systems Command and PEO for Unmanned Aviation and Strike Weapons. In December 2014, he became the 25th chief of Naval Research with concurrent flag responsibilities as director, Innovation Technology Requirements, and Test & Evaluation.

Winter holds a master's degree in computer science from the Naval Postgraduate School and another in national resource strategy from National Defense University's Industrial College of the Armed Forces; and a Level III certification in Program Management and Test & Evaluation from the Defense System Management College.

His personal awards include the Legion of Merit (3), Defense Meritorious Service Medal (2), Navy Meritorious Service Medal (2), Navy and Marine Corps Commendation Medal (4), Joint Service Achievement Medal (2), Navy and Marine Corps Achievement Medal, Air Force Acquisition Excellence Award, Southwest Asia Service Medal, Kuwait Liberation Medal, and various unit and sea service awards.

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HOUSE ARMED SERVICES COMMITTEE
SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES
U.S. HOUSE OF REPRESENTATIVES

DEPARTMENT OF THE AIR FORCE

PRESENTATION TO THE HOUSE ARMED SERVICES COMMITTEE
SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES

U.S. HOUSE OF REPRESENTATIVES

24 February 2016

SUBJECT: Fiscal Year 2017 Air Force Science and Technology

STATEMENT OF: Dr. David E. Walker, SES
Deputy Assistant Secretary
(Science, Technology and Engineering)

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INTRODUCTION

Mr. Chairman, Members of the Subcommittee and Staff, I am pleased to have the opportunity to provide testimony on the Fiscal Year 2017 Air Force Science and Technology (S&T) Program and our efforts to innovatively and affordably respond to warfighter's needs now while simultaneously creating the force of the future.

As you heard the Secretary of Defense state recently, the Fiscal Year 2017 President's Budget takes the "long view" required to sustain our lead in full-spectrum warfighting. During the Acquisition Reform hearing in early January, we shared thoughts with the full Committee on the changing character of war and the inevitability of increasingly rapid change. On one side, the Department is thinking about the long-term capabilities necessary to fight in 10, 20 or 30 years down the road. On the other side, we've recognized that the relentless pace of change increases complexity and decreases predictability in warfare. As stated in the Air Force *Future Operating Concept*, "no technology or technique will eliminate the metaphorical fog and friction of warfare, and no military advantage will go unchallenged by adversaries seeking to achieve their objectives and deny us ours."

Given this environment of rapid change, how do we as an Air Force—and as a Department as a whole—ensure we have the capabilities we need to dominate the current fight, prepare for the future fight, and/or deter it from happening at all? We believe the answer is to bring a new level of agility and innovation into our capability development processes, workforce and infrastructure. As highlighted in the Air Force Strategy, *America's Air Force: A Call to the Future*, strategic agility allows us to rapidly adjust to evolving threat environments faster than our adversaries and can help us counter uncertainty. The Air Force's efforts in this area, many of which are described in this statement, support the building blocks of the Department's Third Offset Strategy and our Fiscal Year 2017 Air Force S&T Program has alignment to the Long Range Research and Development

Planning Program initiatives. From an acquisition perspective, our Air Force efforts also incorporate and support the Better Buying Power (BBP) 3.0 initiatives under the leadership of Mr. Frank Kendall, Under Secretary of Defense for Acquisition, Technology and Logistics (AT&L). The BBP 3.0 initiatives are endeavoring to strengthen our ability to innovate, achieve technical excellence, and field dominant military capabilities.

The following statement provides an overview of the Air Force's move toward strategic agility in capability development through reinvigorating development planning, maximizing the impact of our robust S&T program (game-changing, enabling, relevant, and rapid technologies), increasing efforts in experimentation and prototyping, and leveraging the contributions of our entire world class workforce and infrastructure.

AIR FORCE FISCAL YEAR 2017 S&T PROGRAM AND ASSOCIATED EFFORTS

As our budget request highlights, Air Force senior leaders are committed to science and technology and embracing new paradigms in capability development. The Air Force Fiscal Year 2017 President's Budget request for S&T is approximately $2.5 billion. This is an increase of $108 million or a 4.5% increase from the Fiscal Year 2016 President's Budget request. We have emphasized research in hypersonic and low cost cruise missile technologies to provide the capability to counter adversary anti-access and area-denial (A2/AD) in support of the Long Range Research and Development Planning Program; advanced air combat missiles; and research in technologies to provide robust position, navigation and timing (PNT) capabilities. The Air Force Fiscal Year 2017 President's Budget request also includes funding in Budget Activity 4 (Advanced Component Development and Prototypes) and in Budget Activity 6 (RDT&E Management Support) to support our prototyping, experimentation, and modeling and simulation efforts. Approximately $62 million for prototyping and experimentation funds the experimentation campaigns chartered by Air Force senior leaders and approximately $285 million funds the Adaptive Engine Transition

Program (AETP). More information on these efforts is provided later in this statement. Approximately $13 million of integrated modeling and simulation funding will be used to build and maintain the tools and virtual environments necessary to conduct development planning, prototyping, and experimentation.

AGILITY IN CAPABILITY DEVELOPMENT

To capitalize on the increasingly dynamic environment, the Air Force is aggressively pursuing a path toward *strategic agility*. At its heart, the term *agility* means the ability to act appropriately within a changing context and captures the attributes of *flexibility*, *adaptability*, and *responsiveness*. Flexibility is the hallmark of airpower, and the adaptability of our Airmen, organizations, operational concepts, and weapon systems has long underwritten that flexibility. We now look to our Airmen to foster a culture which values anticipation over reaction and shaping over responding. Achieving greater agility in how we organize, train, equip, and employ our Air Force provides a *strategic* advantage over potential adversaries. The Air Force is not forging this paradigm shift in capability development simply for our own sake, but for the sake of the joint fight and the Nation.

We're also not starting this endeavor from scratch. Historically, we've used development planning to drive innovation and plan our future. Our reinvigoration of development planning at the Air Force enterprise level gets us back to our roots to formulate truly innovative strategic choices and leverage the attributes of agility in our capability development. Development planning enables us to understand and synthesize future warfighting needs and reconcile those with available and potential capabilities, concepts, and emerging technologies and will be a key process to support Air Force strategic decisions. Key development planning functions to achieve this understanding include: systems engineering to formulate and evaluate viable concepts; operational trade space analysis and definition; technology shortfall identification; S&T needs and gap analysis; and

requirements refinement. In conjunction with development planning, the Air Force is conducting experimentation and prototyping activities which bring together operators, technologists, requirements, and acquisition professionals to explore the full range of multi-domain innovative materiel and non-materiel solution options. These activities provide an environment where our Airmen can take smart risks when exploring innovative ideas.

The Air Force is using an Enterprise Capability Collaboration Team (ECCT) approach to facilitate development planning for our highest-priority mission areas. ECCTs have the freedom to explore concepts with a direct path to senior leadership for quicker decisions on courses of action to increase agility across the enterprise. The ECCTs are leveraging knowledge and expertise residing in the Air Force operational community, acquisition enterprise, the DoD laboratory enterprise, Federally Funded Research and Development Centers (FFRDCs), academia, and industry, as appropriate.

CONTRIBUTION OF AIR FORCE S&T IN AGILE CAPABILITY DEVELOPMENT

The Air Force S&T Program plays an integral role in developing technologies to provide options for our forces of tomorrow and ensuring needed technologies get into the hands of our warfighters today. The Air Force emphasized the role of S&T by dedicating an annex in the Strategic Master Plan which outlines a strategic approach to S&T and the supporting elements necessary to bring forth the next generation of capabilities.

Game-Changing (Revolutionary) Technologies

As outlined in *America's Air Force: A Call to the Future*, we are focusing on several game-changing technologies that can amplify many of the enduring attributes of airpower—speed, range, flexibility, and precision. These game-changing technologies are: autonomous systems, unmanned systems, hypersonics, directed energy, and nanotechnology. The Air Force's S&T efforts in

autonomous systems and unmanned systems provide key support to the realization of the five enablers of the Department's Third Offset Strategy.

Autonomous Systems

Autonomy has the potential to enhance Air Force readiness for increasingly complex, future operating environments. Autonomous systems can provide new approaches to airpower by potentially reducing unnecessary manning costs and time required for critical operations while increasing the range of operations and levels of reliability, persistence and efficiency. While autonomous systems can extend human reach by providing potentially unlimited persistent capabilities without degradation due to fatigue or lack of attention, such increases in machine autonomy requires humans and automated systems to work as a team, with some level of decision-making delegated to the machine counterpart.

Our research seeks to find the right balance of human and machine capability to meet Air Force challenges in the future. To achieve optimal human-machine teaming, the Air Force is developing technologies to enable Airmen and machines to work together, with each understanding mission context, sharing understanding and situation awareness, and adapting to the needs and capabilities of the other. Additional research is focused on understanding human cognition and decision-making and applying these concepts to machine learning. These efforts are developing efficient interfaces for an operator to supervise multiple unmanned aerial system (UAS) platforms and providing cyber operators and intelligence, surveillance, and reconnaissance (ISR) analysts with tools to assist in identifying and tracking targets of interest.

To achieve human-machine cooperation in a complex, contested environment, the Air Force is focused on increasing machine intelligence. Cooperative, distributed system technologies will enable machines to synchronize activity and information. Systems that coordinate location, status, mission intent, and intelligence and surveillance data can provide redundancy, increased coverage,

decreased costs and/or increased capability. Air Force S&T efforts are focused on the coordination and integration of disparate sensor systems across multiple aircraft as well as developing munition sensors and guidance systems that will increase operator trust, validation, and flexibility while capitalizing on the growing ability of munitions to autonomously search a region of interest, provide additional situational awareness, plan optimum flight paths, de-conflict trajectories, optimize weapon-to-target orientation, reduce operator workload, and cooperate to achieve optimum effects. To help ensure safe operations of autonomous systems, the Air Force is researching the architectures and mechanisms to prevent cyber intrusions, and as importantly, developing capability in the system to detect anomalies and validate data. We have initiated research to develop and test techniques to verify the decision-making and logic of the system and validate the system's ability to operate safely and effectively in unanticipated and dynamic environments.

Unmanned Systems

With the advent of unmanned warfighting capability, there is a new path for disaggregation. By removing the operator from the aircraft, unmanned platforms can be made less complex and much smaller. This allows the complexity of the air mission system to be increased, as needed, through composition of multiple, simpler platforms. Mission packages may be composed of specialized, unmanned platforms performing each of the needed functions singly such as global communication, precision navigation, target identification, and weapon delivery. Disaggregated unmanned air systems present a new dimension for achieving the operational agility envisioned in the Air Force *Future Operating Concept* and the Department's Third Offset Strategy.

There are expansive technology requirements to field a disaggregated unmanned system. These systems will have a critical dependence on secure tactical communication to share services across the mission package. They will require a robust combination of onboard autonomy and distributed command and control. To fit high performance functionality on small platforms requires

advanced structural concepts, flexible electronics, and advanced onboard power sources. Other needs are new classes of distributed, collaborative sensors and onboard data fusion. This class of vehicles will also need to navigate safely in airspace as well as launch, refuel, and recover in unique ways.

The Air Force S&T Program is addressing many of these issues. For example, we have multiple efforts to enhance propulsion and power performance for smaller air vehicles and our robust portfolio of autonomy investments discussed earlier in this statement will allow for critical onboard decision-making and enhanced human-machine interfaces. Air Force S&T efforts in this area are focusing on advancing and enhancing rapid and agile manufacturing techniques for these systems. In addition, the Air Force Research Laboratory has demonstrated and fielded multiple approaches to collision avoidance to allow for safe airspace integration.

This class of platforms also presents an ideal context for advancing our capability for rapid, agile development and fielding. One of these efforts, Low Cost Attritable Aircraft Technology (LCAAT), is discussed later in this statement along with other rapid transition and fielding activities. Development can accelerate by establishing new certification standards for these low-cost, limited life airframes. A commitment to open architectures and interface specifications allows for upgradable modularity. Integration of design and manufacturing, coupled with automated and additive construction, opens the door to purpose-built platforms. This unique opportunity for frequent, simplified technology refresh will keep these disaggregated unmanned systems ever-relevant and cost effective.

Hypersonics

Hypersonics are one of the game-changers that provide high-speed options for engaging time sensitive targets, while improving the survivability of Air Force systems. The Air Force is developing technologies for a High Speed Strike Weapon (HSSW) to enable a responsive, long-

range strike capability. These weapons can be employed from fighters and bombers and fly at hypersonic speeds to their intended target on the ground.

The Air Force continues to partner with the Defense Advanced Research Project Agency (DARPA) on two flight demonstration programs for HSSW technologies: Hypersonic Air-breathing Weapon Concept (HAWC) and Tactical Boost Glide (TBG). These programs intend to address three technology challenge areas: air vehicle feasibility, effectiveness and affordability. The HAWC program aims to develop and demonstrate critical technologies and attributes of an effective and affordable hypersonic cruise missile. The TBG program aims to develop and demonstrate technologies to enable future air-launched, tactical-range hypersonic boost glide systems.

The HSSW Technology Maturation (Tech Mat) effort is developing technologies to complement the DARPA-Air Force HSSW demonstrations and to expand the technology trade space in hypersonics. HSSW Tech Mat focuses on longer term enabling and enhancing technologies. Some of these include: ordnance; advanced materials and manufacturing; guidance, navigation, and control; and solid rocket motor technologies.

Directed Energy

The Air Force has invested in directed energy (DE) including high power microwave (HPM) and high energy laser (HEL) technologies to the point that we are now positioned to provide Airmen distinctive and revolutionary capabilities for several Air Force and joint mission areas. With a uniquely focused high power DE S&T organization with a wide range of modern, dedicated facilities and an excellent scientist and engineering (S&E) workforce, including a large number of young military officers, the Air Force is in a leading position in this game-changing area.

We recently initiated S&T efforts to implement DE on small and rapidly maneuvering platforms where size, weight and power scaling are major challenges. This effort, when

accomplished, will provide a force multiplier by placing both kinetic and non-kinetic weapons capabilities on our current platforms.

Lower power laser technologies are rapidly evolving for infrared seeker jamming, improved ISR and target identification, and secure communications in congested and jammed spectrum environments. To make HEL weapon systems useful to the warfighter, our S&T program invests in research for laser sources that include narrow line width fiber laser amplifiers that when combined in large numbers produce weapons class lasers. To complement the laser source development, the Air Force has parallel research in beam control component and system-level technologies; atmospheric compensation, acquisition, pointing, tracking, laser effects; and physics-based end-to-end modeling and simulation. All of these technologies are maturing to a point where the Air Force S&T Program can now address the highly turbulent environment for correcting aero effects on the laser beam from an aircraft. This will be demonstrated by integrating a moderate power laser system into a standard fuel pod for aircraft self-protection applications.

The High Energy Laser Joint Technology Office (HEL JTO) supports all of the Services under Office of the Secretary of Defense (OSD) leadership by translating requirements into technology. The HEL JTO is a key enabler to the HEL community at the component level for laser sources, beam control, lethality, and modeling and simulation. Several advances in the development of high power laser devices like the 100 kilowatt, laboratory-scale Joint High Power Solid State Laser and the Robust Electric Laser Initiative would not have occurred without HEL JTO leadership, joint service collaboration, and adequate funding. The HEL JTO is also developing the Advanced Beam Control for Locating and Engagement program that will advance pointing and tracking through the use of improved sensors and adaptive optics. The Services are leveraging these components and designs for inclusion in future weapon systems.

Air Force HPM S&T will complement kinetic weapons by engaging multiple soft targets and neutralizing communication systems, computers, command and control nodes, and other electronics, with low collateral damage for counter A2/AD in future combat situations. Using the results from the highly successful Counter-Electronics High Power Microwave Advanced Missile Project (CHAMP) Joint Capabilities Technology Demonstration, there is research investigating size, weight and power updates for a more effective, more capable weapon delivering a broader spectrum of microwave effects on a smaller platform. In addition, the Air Force is refurbishing the two remaining CHAMP platforms and investigating options for them to be used by the warfighter to address the vehicle survivability, environment suitability, range, reliability, and maintainability issues highlighted by the Operational Utility Assessment.

Nanotechnology

Emerging research and developments at nanometer dimensions—below 100 nanometers—promise revolutionary technological changes for a wide range of Air Force and DoD applications and platforms by delivering materials, coatings, devices and sensors with new and novel performance. Nanotechnologies to be incorporated within the Air Force platforms are directly relevant to the Air Force technology areas of aerodynamics, mobility, stealth, sensing, power generation and management, smart structures and materials, resilience and robustness, and augmented human performance. In addition, Air Force S&T efforts are investigating how nanotechnologies will impact battlespace systems concerned with information and signal processing, autonomy and intelligence. Our Air Force S&T investment in this game-changing technology will also enable the development of novel materials providing the basis for the design and development of new properties and structures resulting in increased performance, reduced cost of maintenance, and enhanced functionality.

The Air Force is also leveraging advances in nanoscience to enable game-changing computing technologies. For example, our investment in this area includes large-scale symbolic inference models and subsequent computing architecture implementations for affordable, agile, autonomous, and trusted systems capable of ingesting and processing big data to support decision makers. Multifunctional nanoelectronics and nanomaterials involving hybrid and three-dimensional (3D) stacking will provide a 100 times increase in computing density, and enable human-level computing capacity in embedded systems. Ensuring a U.S. industrial base for nanofabrication capabilities will be critical to competitively enabling this functionality in domestic systems. Towards this end, Air Force Research Laboratory researchers are working closely with the nanofabrication facility at the State University of New York Polytechnic Institute to collaborate and exploit advancements in nanoelectronic design and manufacturing, thus shortening the time from concept to fielding to the warfighter.

Enabling Technologies

In addition to these game-changing technologies, the Air Force S&T Program also invests in many enabling technologies to facilitate major advances and ensure maximum effectiveness in the near-, mid-, and far term.

Basic Research

Basic research embraces the challenge set forth by Air Force senior leadership by driving game-changing innovation to achieve the art-of-the-possible. The development of revolutionary capabilities requires the careful investment in foundational science to generate new knowledge.

Air Force basic research sits at the center of an innovation network that tracks the best S&T with our partners in the Army, Navy, Defense Threat Reduction Agency, and DARPA while monitoring the investments and breakthroughs of the National Science Foundation, NASA, the Department of Energy, and National Institute of Standards and Technology. Furthermore, through

open, publishable research that cuts across multiple scientific disciplines Air Force S&Es attend to and collaborate with the best universities and research centers from around the world. Our scientists and engineers seek out the potential military utility of new ideas and concepts to transition game-changing S&T to the Air Force and our partners. The Air Force S&T Program integrates these developments and provides the support to inject scientific results and innovative breakthroughs into the research and acquisition community.

Game-changing capabilities begin with foundational, cross-cutting and revolutionary basic research. For instance, Air Force researchers have performed the first fully resolved direct numerical simulations of the turbulent boundary layers of interest to hypersonic flight. This fundamental research is leading the way to determining the 3D unsteady separation of the flow on control surfaces. The basic research modeling and simulation work is being applied to high fidelity wind tunnel testing and flight data simulation, with additional application to thermally-induced structural distortions on hypersonic weapons.

Live, Virtual, and Constructive (LVC)

Our national security challenges make it imperative that our forces be prepared to meet the challenges of the future battlespace through realistic training environments. The Air Force strategy, *America's Air Force: A Call to the Future*, describes Live, Virtual, and Constructive (LVC) as "one of the more promising paths to agility in operational training and readiness." As such, our Air Force S&T Program is continuing to develop and demonstrate technologies for LVC operations to maintain combat readiness.

The need for LVC is highlighted as training costs are increasing and threat environments become highly complex. In particular, realistic training for A2/AD environments is not available. Past demonstrations of Air Force S&T LVC capability for tactical air have integrated an F-16 networked simulation environment (a virtual simulator) to simultaneously interoperate with a mix

of live F-16 aircraft, other virtual simulations (including the immersive environment known as the Joint Terminal Attack Controller Training and Rehearsal System), and high-fidelity, computer-generated constructive players. This mix of players enabled the real time and realistic portrayal and interaction of other strike package assets and aggressor aircraft with a level of complexity that could not be achieved if limited to live assets, given the expense and resource availability to support the scenarios.

Although the example just discussed is for tactical air, LVC can apply to other operational domains, such as special operations; cyber; ISR; and command and control (C2). A recent example of a successful LVC demonstration is the integration of live Joint Terminal Attack Controllers (JTACs) with live A-10 aircraft in a training exercise. The JTACs were operating within the Joint Theater Attack Controller Training and Rehearsal System and were coordinating air strikes with the A-10 aircraft. For the Air Force medical community, LVC is envisioned to support training for expeditionary medicine, enroute medical care, and schoolhouse medical training. The Air Force Research Laboratory is teaming with the U.S. Air Force School of Aerospace Medicine to review these areas of LVC application.

In Fiscal Year 2017, the Secure LVC Advanced Training Environment (SLATE) effort is planned to continue LVC hardware and software development, 5th generation waveform maturation and Operational Flight Plan (OFP) modification. These S&T efforts will focus on upgrades to range infrastructure and integration of LVC pod/internal form factor for the F-35 which will include a new datalink and Multiple Independent Levels of Security (MILS) encryptor and processors.

Position, Navigation, and Timing

The Air Force is emphasizing S&T efforts in PNT to improve the robustness of military Global Positioning System (GPS) receivers and also developing several non-GPS based alternative capabilities including exploitation of other satellite navigation constellations, use of new signals of

opportunity, and incorporation of additional sensors such as star trackers and terrain viewing optical systems. These receivers provide new navigation options with different accuracy depending on available sensors and computational power.

We are collaborating with DARPA, the Army, and the Navy on the development of future adaptable military navigation systems. In this endeavor, we are promoting technology trends toward more open architectures and software defined radios for navigation systems to address future spiral enhancements and control cost growth of embedded GPS-inertial avionics. We are also partnered with DARPA on inertial and clock size, weight, power, and cost (SWaP-C) advances via a variety of technological approaches and in starting a new very low frequency (VLF) terrestrial beacon based navigation and timing research effort. We have also conducted multiple GPS-denied vision-aided inertial flight experiments that demonstrate a small percent of distance traveled error accumulation in position accuracy.

Manufacturing Technologies

The Air Force's Manufacturing Technology program has focused on promoting technologies for an agile, next generation manufacturing industrial base with strategic benefits in efficiency, affordability, and capabilities in Air Force warfighting products. The program strategically aligns key agile manufacturing objectives including: 1) moving manufacturing considerations earlier in the design cycle to reduce acquisition cost and risk; 2) enabling seamless lifecycle management through an integrated digital thread to document and improve process control, optimization, and manufacturing agility; 3) integrating the industrial base enterprise to predict, identify, and react to supply chain issues; and 4) creating the factory of the future with flexible, smart machine cells and assembly processes that are efficient even at low volume production. Several agile manufacturing initiatives are now underway. The Agile Manufacturing for ISR (AMISR) AgilePod effort is focused on developing and implementing advanced manufacturing techniques to enable affordable, low volume production of open architecture multi-sensor ISR pods. The Air Force Manufacturing

Technology Program is also key to the LCAAT effort to develop and demonstrate a capable, attritable aircraft for less than $3 million without mission systems. More information on this effort is provided later in the statement.

The Air Force is continuing support to the Manufacturing Institutes as part of the National Network for Manufacturing Innovation. The Air Force Research Laboratory participates on Technical Advisory Boards and Government Advisory Boards and provides subject matter experts (SMEs) for source selection and project execution. The two newest institutes are the American Institute for Manufacturing-Integrated Photonics (AIM-IP) and Next Flex for flexible hybrid electronics. AIM-IP was established in August 2015 and is focused on developing novel manufacturing processes for integrated photonic devices. Air Force applications include but aren't limited to lasers, detectors, waveguides/passive structures, modulators, electronic controls and optical interconnects. NextFlex was established in September 2015 and is focused on developing highly tailorable devices on flexible and stretchable substrates. Air Force applications include integration of flexible components such as circuits, communications, sensors and power with more sophisticated Silicon-based processors. Both institutes utilize a "shared" leadership model with an Air Force Research Laboratory Chief Technology Officer (CTO) responsible for the technical vision of the institute.

Material Technologies (Sustainment)

At all stages of defense planning sustaining the force remains a priority. The average age of our air and space forces is at a historic high and will continue to increase. For this reason the acquisition life cycle of our defense systems needs to ensure planning for sustainment early in the cycle. For fielded systems the need to improve sustainability and increase life cycles is also imperative. This is an area where we can and must be more innovative and less risk averse in discovering and demonstrating additional methods to sustain our existing assets.

Air Force S&T is directly contributing to this fight. We are committed to developing new technologies to sustain our current systems as evidenced by our work developing new materials, manufacturing processes and Non-Destructive Inspection (NDI) techniques, and improving maintenance and repair diagnostics, and analysis tools for life prediction and extension, fleet management, and decision-making. For example, data mapping analysis technology will be demonstrated on the B-1B Lancer to incorporate NDI and additional maintenance and repair data. Additionally, the C-5 Galaxy will be our test bed for an environmental data/dwell time model that will more accurately estimate the state and location of an aircraft's corrosion.

Relevant Technologies

Cyber

The execution of Air Force core missions to deliver airpower relies on the ability to effectively operate in cyberspace. Operations in cyberspace can magnify military effects by increasing the efficiency and effectiveness of air and space operations across all domains. However, the cyberspace domain is becoming increasingly contested and denied and the Air Force faces risks from malicious insiders, insecure supply chains, and increasingly sophisticated adversaries.

Air Force S&T efforts in mission assurance are pursuing survivability and freedom of action in contested and denied environments through enhanced cyber situational awareness for air, space, and cyber commanders. Current foundational research focuses on detection and protection of cyber penetration into Air Force mission systems. This work concentrates on stopping attacks before systems are fully compromised. Going beyond the current strategies of firewalls and virus/malware detection, the technologies being developed will understand attacks, discover persistent threats, and use a framework to allow resources to collaborate on a defense. This will allow the Air Force to maintain operations in a contested cyber environment. The research provides an array of foundational technology options to Air Force cyber needs and requirements.

We are also conducting research in agility and survivability to develop technologies that disrupt adversaries' cyber "kill chain," along with their planning and decision-making processes, and hardening our cyber elements to improve the ability to fight through, survive, and rapidly recover from attacks. Air Force S&T efforts are improving our agility within cyberspace by investigating techniques called moving target defenses and by providing a C2 structure to plan, assess, and execute a coordinated defense for our Air Force networks. Our efforts are developing visualization technologies that will enable a global common operational picture of complex cyber capabilities that can be readily manipulated to support Air Force mission-essential functions. Other cyber efforts seek to identify critical human skills and abilities for cyber warriors and develop a realistic distributed network training environment.

The Air Force is developing secure foundations of computing to provide operator trust in Air Force weapon systems, including a mix of embedded systems, customized and militarized commercial systems, commercial-off-the-shelf (COTS) equipment, and unverified hardware and software developed outside the U.S. To counter the lack of hardware-based cyber security features which allow exploitation of software vulnerabilities, Air Force S&T is developing and testing a secure central processing unit (SCPU). The resulting government-owned intellectual property could be used to secure future embedded systems such as remotely piloted vehicles or other mission critical or autonomous systems.

Additionally, research into formal verification and validation of complex, large scale, interdependent systems, as well as vulnerability analysis, automated reverse engineering, and real-time forensics tools will enable designers to quantify the level of trust in various components of the infrastructure and to understand the risk these components pose to the execution of critical mission functions.

Assured Communications

The Air Force S&T Program is investing in many areas to assure communications across our domains. We are developing technologies to counter global threats to mission performance (spectrum congestion and jamming), increase capacity over longer range air-to-air with military-grade security, and maintain or increase available bandwidth through dynamic spectrum access to new portions of the radio frequency (RF) spectrum, alleviating pressure on DoD spectrum allocations. Future access to the new spectrum will increase DoD communications architecture capacity and affordability, by requiring fewer expensive, high capacity gateways. Additional bandwidth will also allow improved anti-jam communications performance and higher frequency communications, which will reduce scintillation losses for nuclear command and control. The performance enhancements will directly improve the ability of remotely piloted vehicles to transmit images and data (ISR), improve C2 assurance, and increase communications support to Air Force core missions.

We are building upon ongoing research in several technical areas, such as V/W band experiments for high capacity satellite communications, non-proprietary multi-gigabit data link, Joint Warfighting Integrated Network operations, and advanced anti-jam waveform development for next generation software defined radio frequency systems. We have initiated a new effort to develop the specification and reference architecture for a revolutionary new networked directional data link for airborne systems. These new inexpensive and interoperable radios/waveforms will be able to survive and operate in future contested environments. Our approaches will leverage cost effective commercial best practices tailored to rapidly deliver revolutionary new mission capability. For example, developing a Waveform Development Language baseline will encourage competition, increase interoperability, enable dynamic on-demand assured connectivity, and drive down the cost

of developing/testing waveforms. It will steer away from proprietary and single-use solutions and rather focus on developing technology that can be built upon and that will serve multiple purposes.

The Air Force is the primary Service responsible for the modernization, sustainment and the technological advancement of nuclear command, control and communications (NC3) systems since we own approximately 75 percent of the Nation's NC3 systems. The Air Force S&T Program is investing in the Assured Communication for Nuclear Command and Control (ACNC2) effort to address key aspects of technological advancement with the goal of achieving a significant return on investment for the Air Force's key stakeholders. The ACNC2 effort will provide the warfighter with a full understanding of the anti-scintillation characteristics of the V/W bands for survivable beyond-line-of-sight (BLOS) communications; adaptive digital signal processing technologies for higher performance in existing and next-generation systems; survivable multiple levels of security and information management solutions for the Air Force nuclear enterprise; and an unprecedented capability to perform modeling, simulation and emulation for end-to-end NC3 operational assessment.

Electronic Warfare

Electronic warfare, conducted by manipulating the electromagnetic spectrum, can negate the integrated air defenses of our adversary and allow us to conduct missions in an A2/AD environment. This requires ways to defeat new sensors operating across the electromagnetic spectrum, with more elaborate detection methods, and greater computational, networking and cyber capabilities of adversaries. These capabilities defeat the detection and engagement from threat systems using RF, Electro-Optical (EO), Infrared (IR), and thermal technology.

Air Force S&T efforts in this area have reduced size, weight, and power (SWaP) and improved the algorithms in the Visible Missile Warning Sensor (VMWS) development. The sensor performed very well at live-fire tests in August 2015 and the requirements and design for a

Technology Readiness Level (TRL) 6 sensor are underway. The Air Force Research Laboratory also incorporated improvements to the Proactive infrared countermeasures (IRCM) testbed and demonstrated multi-spectral detection and identification of targets at range. Tests will continue to refine the algorithms and the capability will be incorporated into a Proactive Advanced Technology Demonstration (ATD) slated to begin in Fiscal Year 2017.

Long Distance Sensing

While over the past decade we have been able to conduct airborne ISR operations outside of the lethal range of air defense systems, we do not expect this to be the case in the future. Today's foreign Integrated Air Defense Systems (IADS) have increased lethality and significantly improved engagement capabilities that will force ISR aircraft to fly at longer stand-off distances. With distance limiting the ability to accurately detect, identify, and geo-locate targets the effectiveness of current precision weapons will be reduced. The Air Force S&T program is investing in improving our long standoff sensing capability and adequately addressing the challenges of extended range ISR collection.

The Identification at Range Integrated Sensor (IRIS) program has made excellent progress over the last year and is on track for long range imaging demonstrations in the Fiscal Year 2016 and 2017 time frame. IRIS is a synthetic aperture Laser Radar (LADAR) program that seeks to provide target identification through geometric imaging at ranges and resolutions exceeding the geometric imaging limits of conventional apertures. Significant progress has been made in the transceiver development, image formation algorithms, and modeling and simulation.

Hydrocarbon Boost

The Hydrocarbon Boost Demonstration (HCB) effort is expected to result in the most advanced liquid rocket engine technologies in the world. The engine cycle used is 30 percent more efficient than that used in all previous and current U.S. hydrocarbon fueled rocket engines.

Last year, the program tested a sub-scale pre-burner. Numerous lessons learned at this scale at a fraction of the cost were applied to enable successful completion of the preliminary design of the full-scale pre-burner that will be used in the final demonstration. In addition to being a part of the hydrocarbon boost final demonstration, the Air Force-developed full-scale preburner will be tested at the NASA Stennis Space Center facilities. Full-scale preburner testing will enable the testing of the full-scale thrust chamber combustion stability rig. This testing should occur in 2017 and will provide additional data for the program. The full-scale pre-burner critical design review is currently scheduled to be completed in May 2016. We completed preliminary design of the turbopump assembly, the most difficult component, and will conduct the critical design review in June 2016. The HCB demonstration is also validating new physics-based modeling, simulation, and analysis tools we developed in an earlier program and is already having an impact on Industry. The HCB demonstration is part of the Rocket Propulsion 21 program, a coordinated program chaired by OSD and NASA with the three Services and industry aimed at improving rocket propulsion technology for the nation.

Munitions

The Air Force is investigating new missile technologies to support advanced capabilities for future platforms in the 2030 timeframe. One of the new weapon concepts being explored is the Small Advanced Capabilities Missile (SACM). The SACM will be affordable and provide high loadouts compared to current air-to-air missiles. Another of these new concepts is the Miniature Self-Defense Munition (MSDM). The MSDM would enhance future platforms self-defense capability, without impacting the primary weapon payload.

Space Situational Awareness (SSA)

To help build a holistic national SSA capability, the Air Force's S&T investment is designed to leverage our in-house expertise to innovate in areas with short-, mid- and long-term impact that

are not already being addressed by others. As part of our long history of proving new technologies in relevant environments, the Automated Navigation and Guidance Experiment for Local Space (ANGELS) program examines techniques for providing a clearer picture of the environment around our vital space assets through safe, automated spacecraft operations above Geosynchronous Earth Orbit (GEO). Equipped with significant detection, tracking and characterization technology, ANGELS launched in 2014, successfully maneuvered around its booster's upper stage and explored increased levels of automation in mission planning and execution, enabling more timely and complex operations with a reduced footprint.

We also have investments in S&T for ground-based optical SSA. The Air Force currently has two unique 3.5 meter class telescopes that it uses both to conduct research in characterizing space objects in low earth orbits up to GEO orbits and to support various customers in providing near real-time data on such satellites. One of the systems is located at the Starfire Optical Range (SOR) on Kirtland Air Force Base, New Mexico and the other is located at the Maui Space Surveillance System (MSSS) on the island of Maui, Hawaii. These sites are complementary SSA sites: technically, geographically, situated in different atmospheric conditions, and providing critical data to our space warfighters on the health and status of many satellites. Recent breakthroughs have provided outstanding images during daylight hours which allow us to support Air Force Space Command with desired information in a much shorter timeframe.

In addition, the Air Force is developing key enabling S&T capabilities for data integration, multi-sensor fusion, space object and event characterization, and threat indications and warning for enhanced SSA. The Air Force's Multi-int Activity Pattern Learning and Exploitation (MAPLE) suite of tools, already in operational use in the intelligence community, are currently being enhanced to provide advanced multi-intelligence fusion, satellite characterization, and space system behavioral analysis capabilities for "left of the event" recognition of anomalous activities for more

timely warning and assessment of evolving space events. Rapid prototype fusion, characterization, assessment, and decision support capabilities have already been successfully demonstrated using passive radio frequency and electro-optical SSA data and are being further developed for planned transition to Joint Space Operations Center (JSpOC) Mission System (JMS) Increment 3.

Space Resilience

The Air Force also seeks to explore and mature a number of space resilience technologies in a relevant environment through on-orbit space experimentation. Space experimentation affords a unique opportunity to inculcate resilience into nearly all phases of the acquisition lifecycle from design and build to employment and tactical operations, while still balancing those objectives with technical risk inherent to S&T. It additionally requires integration and exercising of all space system segments (ground, link, space), providing an invaluable breadth of education for the growing base of space professionals.

Through legacy experiments such as XSS-11, TacSat-3 and ANGELS, the Air Force has demonstrated satellite resiliency concepts including responsive proximity operations ahead of inspection and satellite, repair, real time data to Combatant Commanders and monitoring of the local space environment. The Air Force's next major S&T flight endeavor is a collection of experiments called ESPA-Augmented GEO Laboratory Experiment (EAGLE) expected to launch in early Fiscal Year 2018. The host platform for EAGLE transforms a basic EELV-Secondary Payload Adapted (ESPA) ring into a highly capable satellite bus demonstrating resiliency as a space access multiplier, by hosting and/or "forward deploying" additional secondaries into optimized orbits at times of our choosing. Additionally, the concept supports growing calls for more distributed, diverse and proliferated system architectures to better enable space resilience. EAGLE will contain multiple experiments to include tactical awareness and warning, onboard anomaly assessment, deployable self-inspection capabilities, and advanced launch detection capabilities.

We are also continuing the Navigation Technology Satellite-3 (NTS-3) program, which will demonstrate a range of technologies for potential inclusion in Block 4 of the GPS constellation. Equipped with advanced digital payloads and antennas, NTS-3 is designed to provide critical PNT capabilities in GPS-denied environments. Additionally, NTS-3 is being developed to showcase the first purpose-built cyber resilient space system, and will demonstrate persistent PNT capabilities in a cyber-contested environment.

Spacecraft Propulsion

The Air Force is investing in propulsion technologies that will greatly increase the flexibility and resiliency of military satellites. Our S&T program invests in research through the regime of spacecraft propulsion to include: flight programs; advanced electric and chemical propulsion; modeling, simulation, and analysis; and plume phenomenology and signatures. The Air Force has transitioned spacecraft propulsion technologies to most of the nation's National Security Space systems since the 1980s. The latest system to be flying Air Force spacecraft propulsion technology (Hall Effect Thrusters) is the Advance Extremely High Frequency (AEHF) satellite. An AEHF satellite was recently in the news when the on-orbit Hall Effect Thrusters had to be used to put the satellite into its proper orbit when the primary orbit raising thruster failed. Most recently, the Air Force Research Laboratory, the Rapid Capabilities Office, SMC, and industry partners teamed to quickly modify and characterize the thruster (XR-5) used on the AEHF satellite and test it on orbit using the X-37B reusable space vehicle. The modified thruster (XR-5A) incorporates modifications which improve performance and operating range. The Air Force has matured Hall Effect Thrusters and is now engaging in research into multimode thrusters in the form of Field Reverse Configuration thrusters. These multimode thrusters are capable of highly efficient, low thrust operations when needed to do station keeping while simultaneously being able to provide high thrust when needed to maneuver quickly, all using a single propellant.

Rapid Innovation (Responsive) Technologies

As the Secretary of Defense recently stated, we don't have the choice between current fights and future fights—we have to do both. The Air Force S&T Program has had a long history of rapid innovation projects responding to senior leader-identified urgent needs. We have diligently refined the process based on lessons learned over nearly a decade of such projects; carefully optimized the process to rapidly produce cost-effective and operationally suitable prototypes; and leveraged Congressionally-authorized funding sources and non-traditional defense communities.

For example, the Air Force Research Laboratory Rapid Innovation Process leveraged funding authorized by Section 219 to develop the Long Endurance Aerial Platform (LEAP). LEAP provides a revolutionary, low-cost, low acoustic signature, persistent aerial ISR capability to address Combatant Command and U.S. Special Forces ISR gaps by converting a proven, fuel-efficient Light Sport Aircraft into an Unmanned Aerial System (UAS). The Air Force Research Laboratory completed the development and flight testing of the Spiral II design which has a takeoff weight of 1,650 pounds, endurance of more than 30 hours and carries a BLOS satellite communications, command and control (SATCOM C2) data relay along with day/night imaging full motion video and radio direction finding payloads. Based on the success of these tests, an operational evaluation of the system in theater was requested by U.S. Special Operations Command and funded by the Office of the Undersecretary of Defense for Intelligence. The Laboratory procured the hardware for a complete system of four air vehicles and payloads in preparation for deployment.

The Air Force S&T Program is also working to dispel the myth that rapid capabilities are always less affordable. For example, the LCAAT program is leveraging recent advances in advanced manufacturing, such as 3D printing, to rapidly design, build, and field near-term expendable or limited-life unmanned air platforms as single assets or in autonomous or

manned/unmanned teams to detect, deny, and/or disrupt the enemy. This approach bends the cost curve in our favor by enabling the U.S. to deploy weapons systems to destroy or degrade the systems of our adversaries and protect those of our armed forces and of our allies at a small fraction of the cost of current manned and re-usable systems. The low cost attritable aircraft will provide an A2/AD operations capable system, and offer near-term ISR/strike capability in remote regions where forward basing is difficult or prohibited.

The LCAAT program is seeking to change the approach of the typical DoD acquisition process by enabling constant refresh and increased flexibility through close engagement and collaboration with innovative private and public businesses and revolutionary small, non-traditional businesses to reduce cycle time as well as cost. The attritable aircraft concept will offer a game-changing approach to "on-demand" system manufacturing by leveraging open systems architecture, COTS, and distributed manufacturing concepts that will reduce market barriers to entry for new technology capability and enable rapid and agile acquisition.

The Defense Rapid Innovation Program has also been an excellent means for the Air Force to communicate our areas of critical need and solicit vendors to respond with innovative technology solutions. The program continues to help us strengthen the lines of communication between the Program Executive Officers, warfighters, S&T community, and industry. We have done this under full and open competition with preference given to small businesses. We have now completed four solicitations and are in the process of making awards under the fifth solicitation. The results have been noteworthy. From the time Congress first authorized the defense rapid innovation program, the Air Force received over 3,200 white papers from all 50 states in response to our topic areas. With available funding, as of December 2015, we have invited 234 proposals and made 112 awards. Additional awards will be made this spring under the Fiscal Year 2015 program. Several of our projects have had significant success in the current fight. For example, one of our projects has more

than doubled the target detection capability of our MQ-1 Predator. This capability deployed in September 2015 and is currently supporting Operation Inherent Resolve. The new capability involving Airborne Cueing and Exploitation significantly reduces analyst workload, enabling each of them to be more effective and efficient. Other agencies are benefitting from this project as well. The National Geospatial Agency is taking the results from this Defense Rapid Innovation Program effort and further expanding it to support a full spectrum capability and the Army is integrating the improved code onto their platforms.

The Air Force S&T community is also in talks to fully leverage the work of the Defense Innovation Unit-Experimental (DIUx) located in Silicon Valley, California. Researchers involved with the Air Force Research Laboratory Rapid Innovation Process have agreed to conduct "quick look" assessments of technologies discovered by the DIUx to determine validity of further collaborative engagements. The Air Force Research Laboratory Small Business Office has also begun discussions related to technology transfer processes to determine the feasibility of licensing laboratory inventions to startups and academia in Silicon Valley similar to how it is accomplished in both the Dayton, Ohio and Rome, New York areas. This office is also investigating ways to partner in the Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) realm.

EXPERIMENTATION

As discussed earlier in this statement, experimentation is truly the engine of our reinvigorated development planning efforts. It enables the unfettered exploration of alternatives in future environments and involves operators, technologists, requirements, acquisition professionals, and others collaborating from beginning to end in a truly integrated fashion. Campaigns of experimentation are not staged, one-off events; but a series of progressive and iterative activities designed to build knowledge and provides a method to rapidly evaluate capability concepts that

may involve using existing systems in new ways through changes in tactics, techniques, and procedures or in new combinations with other systems and enabling technologies. The campaigns will conduct live exercises, wargaming, modeling and simulation, and virtual and hardware prototyping to assess concepts and advanced technologies. Robust experimentation enables the Air Force to explore implications of disruptive technologies and employment of existing systems and technologies in new ways.

The Air Force is currently conducting four pilot experimentation campaigns: Close Air Support (CAS); Directed Energy (DE); Data to Decisions (D2D); and Defeat Agile Intelligent Targets (DAIT). The D2D and DAIT campaigns are supporting the Air Superiority 2030 ECCT. These experimentation campaigns are designed to provide timely empirical data to enable strategic investment decisions and to reinvigorate the culture of experimentation within the Air Force.

The objective of the CAS Experimentation Campaign is to characterize the Air Force's ability to conduct CAS and explore concepts through experimentation. Results from the CAS Experimentation Campaign are expected to enhance the joint capability to perform CAS in a variety of operational environments and across a range of timeframes. The campaign formed along three distinct lines of effort: 1) localized battlefield networking; 2) JTAC and pilot simulator training enhancements; and 3) determination of the optimal mix of CAS weapons and platforms. The Air Force conducted experiments to communicate a common understanding of the battlefield between ground and air at various distances. Initial experimentation results have demonstrated that a remotely accessible internet protocol (IP) network can be used to enhance Tactical Data (Link 16) with National Technical Data and improve CAS targeting identification. CAS experimentation also improved joint training through LVC demos and enhancements. Competency based training scenarios at the JTAC Dome, which is a high-fidelity, fully-immersive, realistic training and rehearsal environment with real-time sensor, simulator, and database correlation, have benchmarked

standard JTAC competencies. LVC experimentation has connected live A-10, F-16, and AH-60 platforms with virtual MQ-1s in the constructive Modern Air Combat Environment to validate JTAC training benchmarks in a Distributed Mission Operations Network. Future CAS munitions experimentation for testing on the range and in a LVC environment is also being planned. The CAS Experimentation Team is exploring emerging weapons concepts to improve the effectiveness of each pass. Several flight demonstrations are planned for Fiscal Year 2016 and Fiscal Year 2017 to ensure near-, mid-, and far-term weapons development is consistent with future CAS mission requirements.

The Air Force is also conducting the DE Experimentation Campaign to inform senior leadership on strategic investment decisions in this technology area. The Air Force S&T investment in DE technologies has placed us at a point where we can take the concepts and capabilities out of the laboratories and put them into the hands of our warfighters. The campaign is exploring a broad range of DE-enabled concepts through a series of experiments using constructive and operator-in-the-loop simulations and live exercises to understand the interplay of technologies, concept of operations (CONOPS), and doctrine in close collaboration with operators and technology developers. One effort of the DE Experimentation Campaign involves exploring the value of employing a ground-to-air DE hard kill weapon as part of an integrated air defense system. We are doing this in collaboration with the North American Air Defense Command (NORAD) of U.S. Northern Command (NORTHCOM) to explore how advanced technologies could potentially improve its National Capital region air defense capabilities. We are developing and evaluating kill chain CONOPS, performing live fire tests against multiple targets, addressing policy issues, and exploring system integration with existing command and control and guidance systems. A related effort involves experimentation with employment of an air-to-ground HEL weapon system on an AC-130 gunship. We will execute this experimentation in close collaboration with the Air Force

Special Operations Command to assess and deepen our understanding of system performance characteristics, airborne platform integration considerations, and CONOPS. In addition, we will identify and work through important policy-related issues, determine associated infrastructure requirements for a deployed system, and explore residual operational capabilities for continued experimentation and operational observations. The body of knowledge gained through these efforts will identify key risk areas and technology needs to better focus our research and accelerate the realization of HEL capabilities across a range of systems and platforms.

The two additional experimentation campaigns being planned are in response to Air Superiority 2030 ECCT direction. The D2D experimentation campaign will explore various concepts to provide the right data to decision-makers in the time and manner required and the DAIT experimentation campaign will explore new technology-enabled concepts to defeat challenging targets.

PROTOTYPING

Prototyping is a valuable tool for development planning and experimentation as it enables evaluation of design, performance and production. Prototyping activities are useful at various levels of technology maturity—specifically, concept prototypes for the early stages to assess feasibility, development prototypes to test advanced concepts and integrated capabilities, and operational/fieldable prototypes that look toward the production and deployment stage and satisfying operational needs. The Air Force has recognized that engaging operational users intimately involved in need analysis, solution conceptualization, and prototype development enables delivery of a suitable prototype with all the right attributes to satisfy the user need. Furthermore, a rapid spiral development process that incorporates experimentation and prototyping allows the design to evolve quickly based on lessons learned during operations.

One successful rapid prototyping effort is our recent project to improve Convoy C3 and Situational Awareness. In response to a request from 20th Air Force and Air Force Global Strike Command, the Air Force developed and delivered the first spiral of a convoy communications and situational awareness solution. This system provides a self-configuring, self-healing mobile network that allows the members of a nuclear convoy to share voice and text chat messages, imagery from on-vehicle cameras (including overhead imagery from supporting UH-1N helicopters), moving map displays, and reach-back to a command and control center. After approval to prototype a specific design concept was received, a prototype system was delivered in less than six months to operational users at the 90th Missile Wing, F.E. Warren AFB, Wyoming. The wing then successfully conducted a Limited Operational Demonstration and Evaluation that led to a follow-on effort to fully adopt the system and employ it at all three 20th Air Force missile wings. In parallel with this deployment to all three missile wings, the Air Force Research Laboratory implemented product improvements in the system based on lessons learned from the Operational Demonstration and Evaluation. This second spiral of the system design has been selected for full-scale development with support from Air Force Global Strike Command and the 20th Air Force. The full-scale deployment is on-track for early calendar year 2016 completion.

The Air Force's Adaptive Engine Transition Program (AETP) is building on several years of rigorous adaptive engine technology maturation, including significant industry cost share, and is an excellent example of prototyping to reduce risk prior to Engineering and Manufacturing Development (EMD). Following the highly successful S&T efforts in the Adaptive Versatile Engine Technology (ADVENT) and Adaptive Engine Technology Demonstration (AETD) programs, the AETP represents a $2 billion next generation jet engine demonstration and validation program that will advance designs through extensive ground testing for future integration and flight test. The Fiscal Year 2017 $285 million Air Force funding for this program is in Budget Activity 4

(Advanced Component Development and Prototypes). Under this effort, awards will be made to two contractors in Fiscal Year 2016. Awarding to two contractors will help ensure that the most cost-effective solutions to the challenges of engine operability, durability, sustainability, and air platform integration are achieved, while reaching the fuel efficiency and thrust goals set for the program. Additionally, two contractors developing designs will help sustain a healthy domestic and competitive industrial base, enabling the Air Force to have multiple vendors, including second and third tier vendors, to meet development and production needs for legacy and future platforms.

Since the U.S. has no monopoly on technical expertise, we are also actively engaged in the international community in prototyping efforts. Through these relationships, opportunities are identified to leverage investments, advance capabilities, produce standards for interoperability, and avoid technological surprise. For example, with the four current 5-Power Project Agreements, the U.S. invests $4.2 million each year with our partners providing an additional $8.3 million each year. These collaboration efforts have resulted this year in a new agreement with Italy and Germany to develop a prototype Small Scalable Kinetic Weapon. This real-time, adjustable UAV-delivered weapon could be used to limit collateral damage in urban environments.

On all of our efforts in this area we're working closely with AT&L's BBP 3.0 efforts to reinvigorate the use of experimentation and prototyping for the purposes of rapid fielding of technologically advanced weapons systems, providing warfighters with the opportunity to explore novel operational concepts, supporting key elements of the industrial base, and hedging against threat developments or surprises by advancing technology and reducing the lead time to develop and field new capabilities.

WORLD CLASS WORKFORCE

The world class workforce of the Air Force science, technology and engineering community continues to be our most important asset. We recognize that the technological superiority of the Air

Force depends on the technical talent and innovative spirit of our workforce. In order to maintain an agile science, technology, engineering and mathematics (STEM) workforce, two aspects have guided our investments of funding and collaborative energy this year: attracting and inspiring individuals to Air Force STEM careers, and recruiting, retaining and developing the STEM workforce.

Attracting and Inspiring STEM Talent

This past year, the governing body of Air Force STEM, the Air Force STEM Advisory Council (STEMAC), challenged its members to support a dedicated funding source for Air Force STEM outreach programs. Historically, Air Force STEM outreach programs received support through the National Defense Education Program as well as local base-level funding. The Fiscal Year 2017 Air Force S&T Program includes a dedicated effort for funding of STEM outreach activities. These funds will enable outreach programs across multiple installations to dependably offer their excellent STEM programming to K-12 students without fear of competing priorities. Additionally, the Air Force STEM Outreach Office will work toward strategic goals such as improving engagement of traditionally underrepresented communities and developing useful, relevant metrics to assess the impact of K-12 programming.

Attracting and inspiring individuals to Air Force STEM careers is a dynamic mission; as the battlefield shifts and evolves, so too do our workforce requirements. As such, Secretary of the Air Force Deborah Lee James encouraged the STEM Outreach Office to develop outreach programs to target specific technical areas. From this encouragement, the *StellarXplorers* pilot program completed its first national competition in April 2015. *StellarXplorers* is the first space-centered STEM program of its kind to challenge high school students to tackle complicated spacecraft payload flights. As the program grows, the vision is to combine simulated competition to student-led manufacturing of spacecraft hardware.

Recruiting, Retaining and Developing the STEM Workforce

Recruiting, retaining and developing the STEM workforce is vital toward building the future Air Force. The establishment of the Cyber-Spectrum Research and Technology Development Virtual Environment (CSpec-DVE) program showed great progress in this endeavor. CSpec-DVE provides the participating Air Force, Army, and Navy Reserve Officer Training Corps (ROTC) cadets exposure and a means to contribute toward cyber, electronic warfare, and signals intelligence product-oriented research. In this pilot year, 10 universities—in coordination with the Information Directorate of the Air Force Research Laboratory—will oversee and mentor the ROTC cadets. Participating universities include: Georgia Tech University, Louisiana State University, Louisiana Tech University, Syracuse University, Texas A&M University, University of Dayton, University of Houston, Rice University, Southern University and Tennessee State University. CSpec-DVE provides early career development for future leaders by enabling them to contribute to research on cyber, signal intelligence and electronic warfare technical problems.

The ability to recruit, retain and develop the Air Force STEM workforce has been greatly supported and enabled by Congress. The National Defense Authorization Acts of the past several years have provided additional personnel authorities to the S&T community. Specifically, the addition of direct hire authority for candidates with bachelor degrees has been extremely useful in hiring qualified scientists and engineers in less than half the time of traditional hiring methods. We are continuing our efforts to fully implement all of the personnel authorities provided specifically to our community by the Congress.

The Laboratory Personnel Demonstration Project continues to provide the Air Force Research Laboratory a more responsive and flexible personnel system through direct hire authorities, broad banding, the contribution-based pay system, simplified job classification, developmental opportunities, voluntary emeritus corps, among other unique workforce shaping

tools. These authorities have enabled the Laboratory to successfully attract and retain high quality scientists and engineers.

To spark and foster innovation in our current workforce, the Development Opportunity Program (DOP) provides opportunities for Air Force Research Laboratory personnel to acquire knowledge, experience, and expertise that cannot be acquired in the standard working environment. Laboratory personnel have taken advantage of advanced training and education opportunities at academic institutions across the globe. Additionally, Laboratory personnel have contributed to the scientific community as visiting faculty or research scientists at various institutions. We are investigating the expansion of this program to all employees under the Laboratory Personnel Demonstration Project.

LABORATORY INFRASTRUCTURE

Infrastructure focused on S&T is an important component to support innovation and force modernization. The Air Force has made S&T infrastructure a priority as evidenced in the Fiscal Year 2016 and Fiscal Year 2017 military construction (MILCON) processes. Thanks to the approval of the Congress in Fiscal Year 2016, the Air Force Research Laboratory Space Vehicles Directorate will soon have access to a new Space Vehicles Component Development Lab. The Component Development Lab will support space vehicles component development of space power generation, solar arrays and photovoltaic cells, space power storage, space vehicle mechanisms (launch separators and maneuvering components), mechanism controls, space protection including radiation-hardened electronics, and environmental sensors and cryocoolers with four light laboratories, two medium laboratories, and class 1,000 clean rooms required for space vehicle research, development, and experiments. This new facility will consolidate 11 separate S&T infrastructures on Kirtland Air Force Base, New Mexico, increasing the effectiveness and efficiency of work accomplished by the directorate. The Fiscal Year 2017 President's Budget for MILCON

includes the proposed construction of an Advanced Munitions Technology Complex on Eglin Air Force Base, Florida. This laboratory facility is integral to support research and development of sub-scale high speed munitions requiring advanced energetics containing nano and conventional materials. This laboratory would fill a need for the Air Force and the entire DoD as it would be capable of handling and using nano explosive powders or advanced energetics that use nano materials, a capability which does not currently exist in the U.S. today.

Not only has S&T infrastructure received Congressional support in the MILCON process, special Congressional authorities provided to the Laboratory Commander to conduct minor infrastructure projects, known as the "Section 219" authority, have enabled rapid improvements to S&T infrastructure. For instance, an important Section 219 project is under construction at the Air Force Research Laboratory Munitions Directorate located on Eglin Air Force Base, Florida. The Site C-86 range implements a variable height tower which will enable extended slant range measurements, full access to test range geography, optical turbulence distortion reduction, ground clutter elimination, and high value assets protection from over exposure to the elements in support of research, development, and testing of next-generation weapon seekers. This tower will support the delivery of active and passive seeker concepts to defeat adversaries in A2/AD environments as well as urban target environments and long-range targets. In addition, warfighters from Air Combat Command and Air Force Special Operations Command will benefit from use of this tower in their drive to mature technologies for killing moving targets; testing of hard and deeply buried targets seeker development; wire-strike avoidance LADAR technique; helicopter burnout solutions; and sniper identification efforts.

Congress has expanded the Section 219 infrastructure authority to permit the banking of research, test, development and evaluation funds in order to enable projects beyond minor military

construction and we are working diligently to determine the best path forward within Air Force processes to implement this authority.

CONCLUSION

Chairman, Members of the Subcommittee and Staff, thank you again for the opportunity to testify today on the Air Force's move toward strategic agility in capability development through reinvigorating development planning, maximizing the impact of our robust S&T program (game-changing, enabling, relevant, and rapid technologies), increasing efforts in experimentation and prototyping, and leveraging the contributions of our entire world class workforce and infrastructure.

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Dr. Walker is responsible for preparing policy, guidance, and advocacy for the Air Force's annual $2 billion science and technology program. He provides annual testimony to Congress, technical advice and counsel to the Air Force Acquisition Executive, and the Air Force's science and technology recommendations to the Office of the Secretary of Defense. In addition, Dr. Walker is responsible for overseeing a broad range of engineering and technical management policy spanning systems engineering; environmental safety and occupational health; industrial preparedness; and functional management of more than 14,000 military and civilian scientists and engineers.

Dr. Walker retired from an active-duty Air Force career as a colonel in 2006. As a master navigator, he has more than 2,700 hours in 65 different types of aircraft including the RF-4C and the F-15E. He served in a variety of assignments in operations, developmental test and evaluation, science and technology and the Air Staff.

Prior to his current position, Dr. Walker served as Associate Deputy Assistant Secretary of the Air Force (Acquisition Integration), Washington, DC.

EDUCATION
1979 Bachelor of Science degree in aerospace engineering, University of Texas at Austin
1980 Master of Science degree in aerospace engineering, University of Texas at Austin
1984 Squadron Officer School, Maxwell Air Force Base, Ala.
1991 Air Command and Staff College, Maxwell AFB, Ala.
1994 Doctor of Philosophy degree in Aeronautical Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio
1997 Air War College, Maxwell AFB, Ala.
1999 Advanced Program Manager Course, Defense Systems Management College, Fort Belvoir, Va.
2009 APEX Senior Executive Orientation Program, Washington, D.C.
2010 Air Force Enterprise Leadership Seminar, Darden School of Business, University of Virginia, Charlottesville
2011 CAPSTONE, National Defense University, Washington, DC
2012 Senior Managers in Government, Harvard Kennedy School, Cambridge, Mass.

CAREER CHRONOLOGY
1. February 1980 - October 1980, Student, undergraduate navigator training and Tactical Navigation Course, Mather AFB, Calif.
2. October 1980 - June 1981, Student, RF-4C Replacement Training Unit, 33rd Tactical Reconnaissance Training Squadron, Shaw AFB, S.C.
3. June 1981 - May 1984, RF-4C Weapon Systems Officer, 38th Tactical Reconnaissance Squadron, Zweibrucken Air Base, West Germany
4. June 1984 - July 1984, Student, Squadron Officer School, Maxwell AFB, Ala.

5. August 1984 - June 1985, Instructor Weapon Systems Officer, 16th Tactical Reconnaissance Squadron, Shaw AFB, S.C.
6. June 1985 - June 1986, Student, Air Force Test Pilot School, Edwards AFB, Calif.
7. June 1986 - January 1987, Experimental Test Navigator, 6512th Test Squadron, Edwards AFB, Calif.
8. February 1987 - November 1988, Experimental Test Weapon Systems Officer, F-15 Combined Test Force, Edwards AFB, Calif.
9. November 1987 - July 1990, Executive Officer to the Commander, Air Force Flight Test Center, Edwards AFB, Calif.
10. August 1990 - June 1991, Student, Air Command and Staff College, Maxwell AFB, Ala.
11. June 1991 - June 1994, Doctoral Student, Air Force Institute of Technology, Wright-Patterson AFB, Ohio
12. July 1994 - May 1995, Chief, Instructor Training, Curriculum Development, USAF Test Pilot School, Edwards AFB, Calif.
13. May 1995 - July 1996, Deputy Commandant, Air Force Test Pilot School, Edwards AFB, Calif.
14. July 1996 - June 1997, Student, Air War College, Maxwell AFB, Ala.
15. July 1997 - June 1998, Deputy Chief, Common Systems Division, Directorate of Global Power Programs, Assistant Secretary of the Air Force for Acquisition, the Pentagon, Washington, D.C.
16. June 1998 - August 1999, Chief, Agile Combat Support Division, Directorate of Global Power Programs, Assistant Secretary of the Air Force for Acquisition, the Pentagon, Washington, D.C.
17. August 1999 - June 2001, Director, Air Vehicles Directorate, Air Force Research Laboratory, Wright-Patterson AFB, Ohio
18. June 2001 - July 2003, Commander, 412th Operations Group, Edwards AFB, Calif.
19. July 2003 - July 2006, Vice Commander, Air Force Research Laboratory, Wright-Patterson AFB, Ohio
20. July 2006 - September 2008, Director, Material and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson AFB, Ohio
21. September 2008 - May 2011, Associate Director of Programs, Deputy Chief of Staff for Strategic Plans and Programs, Headquarters U.S. Air Force, Washington, D.C.
22. May 2011 - August 2012, Associate Deputy Assistant Secretary of the Air Force (Acquisition Integration), Office of the Assistant Secretary of the Air Force for Acquisition, the Pentagon, Washington, D.C.
23. August 2012 - present, Deputy Assistant Secretary of the Air Force (Science, Technology and Engineering), Office of the Assistant Secretary of the Air Force for Acquisition, the Pentagon, Washington, D.C.

AWARDS AND HONORS
Meritorious Executive Presidential Rank Award
Associate Fellow, American Institute of Aeronautics and Astronautics
Legion of Merit with two oak leaf clusters
Meritorious Service Medal with two oak leaf clusters
Air Medal
Air Force Commendation Medal
Air Force Achievement Medal
Distinguished graduate, ATC Commander's Cup, and Ira Husek Flying Trophy, Undergraduate Navigator Training
Top Gun, Tactical Navigation Course
Distinguished Graduate, RF-4C RTU
Distinguished Graduate and Outstanding Contributor, Squadron Officer School Distinguished Graduate and Raymond L. Jones Award, USAF Test Pilot School Distinguished Graduate, Air Command and Staff College

(Current as of September 2012)

Statement by Arati Prabhakar

Director, Defense Advanced Research Projects Agency (DARPA)

Before the

Subcommittee on Emerging Threats and Capabilities,
Armed Services Committee, U.S. House of Representatives

Department of Defense Fiscal Year 2017 Science and Technology Programs: Defense Innovation to Create the Future Military Force

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NOT FOR PUBLICATION UNTIL RELEASED BY THE SUBCOMMITTEE

Chairman Wilson, Ranking Member Langevin 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 across the Department of Defense (DoD) Science and Technology (S&T) community, with whom we work closely throughout the year.

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. In my testimony today I will describe a number of DARPA programs at various stages of maturity, including some whose products are already being adopted by the military Services and are already making a difference for our warfighters; some that are advancing through the challenging technological frontier that separates the seemingly impossible from the doable—a stage of work that in many ways is the heart and soul of DARPA; and some that are in their earliest phases of development but whose potential to radically change the technological and security landscape is so great that they are already influencing the Department's strategic thinking.

But before I dive into those details, I would like to briefly convey a more personal sense of what is going on at DARPA—an agency that is, after all, not just a collection of programs but a team of about 200 extraordinary individuals. It is a team whose collective energy not only propels DARPA but also invigorates people 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.

So let me say in advance, rather than waiting until my closing as is traditionally the case, how much I and my colleagues at DARPA appreciate the ongoing support and trust that 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.

A CHANGING WORLD

Our senior military and civilian leaders face a world of kaleidoscopic uncertainty today and into any foreseeable future. The daily fare is a noxious stew of violent extremism, terrorism and cross-border criminal activity. At the same time, the actions and the intentions of nation states in every region also demand our focus and attention. 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 defeat if necessary 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. DARPA has participated by sharing its future perspectives on technology, and many programs across the DARPA portfolio will demonstrate the critical core technologies for these new strategies. I will discuss a number of these programs today.

In addition to the geopolitical landscape, the other global context for our work is what's happening in the world of technology itself. The United States is still the largest investor in R&D around the world today. But unlike past decades, we are not alone in our excellent scientific and technical capabilities. With their rising investments, several other nations have first-rate people, labs and industries in various fields. Within the United States, the private sector currently spends $2 for each $1 the Federal Government spends on R&D, and of that federal share, a declining percentage is for defense. It is easy to mourn the passing of an era—now many decades ago—when these trends were reversed. But in fact, they reflect vitally important economic progress both within our Nation and around the world.

Our challenge at DARPA and in DoD is to create a significant advantage for military and national security purposes against this competitive, shifting backdrop. Two principles guide our thinking at DARPA in this regard. One key concept is that the most powerful defense systems will come from the tight integration of the leading edge of commercial technology with 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 is the understanding that U.S. military success will lie in building systems that are designed to evolve, grow and adapt, rather than counting on

technologies that other actors can't get for decades, as in the past. This compels us not just to design a new point of capability, but to design new curves of expanding capability over time. And again, you will see this theme throughout our programs.

The agency's current strategic framework and descriptions of our major areas of investment are outlined in "Breakthrough Technologies for National Security," which also describes DARPA's approaches to ensuring that advances are successfully transitioned to the military Services, commercial enterprises or other research entities for further development in ways that best serve U.S. national interests. Rather than restating those basics, I'd like to focus my testimony today on a number of individual endeavors within DARPA's portfolio of more than 200 active programs. What follows are brief descriptions and progress reports for programs within each of DARPA's three major investment areas—Rethinking Complex Military Systems, Mastering the Information Explosion, and Nurturing the Seeds of Technological Surprise—broken into groups representing each of the three degrees of maturity I mentioned earlier: already being piloted or used ("Adoption and Impact"), currently in development ("Technical Progress") and fresh investment directions ("New Opportunities").

DARPA'S INVESTMENT PORTFOLIO

Rethinking Complex Military Systems

The unparalleled technological capability that has enabled U.S. military and security superiority comes with a price: spiraling increases in complexity. Today, many high-end military platforms are so complex they take decades to produce and years to upgrade. In a world in which pace is inexorably increasing, and in which other economic and manufacturing sectors have recognized the benefits of systems modularity, rapid-fire iterative improvements and faster hardware- and software-system upgrades, the military's current approach to managing complexity is inadequate. It risks leaving the Nation vulnerable to adversaries developing more nimble means of adopting technology.

Today DARPA is turning the tables on complexity, creating engineering architectures and approaches that deliver significantly greater combat power, but with a technical elegance that also allows for flexibility in the field and fast upgrades.

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.

Aircrew Labor In-Cockpit Automation System (ALIAS)
DARPA's ALIAS program is developing a tailorable drop-in kit that would add high levels of automation into existing aircraft and reduce the demand for onboard crew. The program is leveraging the considerable advances that have been made in aircraft automation systems over the past 50 years, as well as the advances that have been made in remotely piloted aircraft technologies, to help shift and refocus pilot workloads, augment mission performance and improve aircraft safety.

DARPA will be working with the U.S. Army Utility Helicopters Project Office to test ALIAS technologies on the Blackhawk platform for potential transition of enhanced automation capabilities to the Army utility helicopter fleet. Among the project's goals are improved handling qualities, improved safety and system reliability and the ability to add apps to introduce new functionality and capabilities into the fleet.

Persistent Close Air Support (PCAS)

Close air support (CAS) has long been delivered to warfighters on the ground by those in the air through coordinating strike details with paper maps and voice communications over a radio. The PCAS program set out to bring the power of digital technology to dramatically improve CAS, starting by adding encryption and military radios to commercial Android tablets and designing easy, nonintrusive upgrades for aircraft. Today, simple versions have been adopted and used in theater, and more fully integrated versions have been demonstrated with Service partners.

The ground component of the PCAS system was first put through its paces by Marines in combat in Afghanistan, with DARPA providing more than 500 systems for testing. Marines in theater subsequently adopted the tablets in the thousands, and field reports documented dramatically improved navigation, situational awareness, fire coordination and communications. Marines are currently using this technology in operations in the U.S. Central Command Area of Responsibility. DARPA has also successfully tested the full PCAS prototype system in a U.S. Marine Corps infantry/aviation training exercise. That demonstration marked the first successful integration of automated, digital, real-time coordination capability into a military aircraft system, including tube-launched munitions, digital data links and advanced software in support of ground forces. Ground forces requested a strike with a few taps on a tablet, and the aircrew delivered digitally confirmed strike four minutes later.

This past summer, DARPA demonstrated its PCAS system on an A-10 Thunderbolt II attack aircraft, marking the system's debut on a U.S. Air Force platform. The tests, which involved 50 successful sorties near Nellis Air Force Base in Nevada, showed that a warfighter serving as a joint terminal attack controller (JTAC) on the ground could, in seamless coordination with a pilot, conduct a CAS operation with each party seeing exactly the same information about the target. The system also featured collateral damage calculation and friendly force location information that could enable improved safety in CAS

operations. In addition, to test the portability of the aircraft component of PCAS, DARPA worked with Army and Army Special Operations partners to perform ground-based demonstrations of the PCAS system on both a helicopter and unmanned aircraft. Army Special Operations Aviation Command is evaluating PCAS for adoption in air-ground capabilities.

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.

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.

Space Robotics and Modular Systems at Geosynchronous Orbit

DARPA's Phoenix program is developing innovative technologies and systems that will make it possible to reimagine operations in geosynchronous Earth orbit (GEO), 35,000 kilometers above the Earth. This is the orbit where the highest priority military satellites operate, and commercial satellites there generate over $100 billion annually in revenue. DARPA is developing a variety of space robotics technologies, including assembly, repair, asset life extension and refueling in the harsh GEO environment; low-cost modular satellite architectures that can scale almost infinitely; and a standardized payload orbital delivery (POD) mechanism designed to safely carry a wide variety of separable mass elements to orbit—including payloads, satlets and electronics—aboard commercial communications satellites. Phoenix has now ground tested the world's first modular satellite, called eXCITe, and prepared it for launch in 2016. In addition, a prototype of a POD mechanism to deliver low-cost rideshare to GEO has also been constructed and is being readied for launch in mid-2017.

High-Capacity Wireless Communications for Remote Environments

Troops in remote forward operating locations typically lack the benefit of a reliable communications infrastructure. And while satellite communications services can provide some capacity to remote areas, they cannot provide the high-bandwidth communications needed to support the amount of data generated by emerging ISR systems. DARPA's Mobile Hotspots program is developing a scalable gigabit-per-second (Gb/s) communications backbone that can be carried on UAVs to connect dismounted warfighters with forward operating bases, tactical operations centers, ISR assets and fixed communications infrastructure. This past year the program made significant progress by building low-power millimeter-wave radios small enough to be carried on UAVs, and demonstrating that these can communicate at tactically relevant ranges at Gb/s rates. We expect to demonstrate a full network built upon these radios later this year in a major Marine Corps exercise.

In related work, DARPA's 100G program is developing the technologies and system concepts to project fiber-optic-class 100 Gb/s airborne data links at ranges of 200 kilometers air-to-air and 100 kilometers air-to-ground from high-altitude long-endurance aerial platforms. Computationally efficient signal processing algorithms are also being developed to meet size, weight and power limitations of host platforms. Recent progress included a demonstration of key components performing to levels suitable to meet overall 100G system goals, during which

DARPA performers set several millimeter-wave modulation and transmission records. The technologies are currently being integrated into a full 100 Gb/s system, to be followed by flight testing.

City-Scale Nuclear and Radiological Monitoring

Terrorist attacks involving dirty bombs or nuclear devices remain a potentially catastrophic threat to security, both at home and abroad. Today, we lack a continuous, wide-area ability to detect such dangers. To that end, DARPA's SIGMA program is developing a networked detection capability that combines sensors and fusion algorithms to enable continuous monitoring of radioactive sources of interest at city-wide scales. The sensors are the size of a smart phone, inexpensive (less than $400 apiece, which is 10 to 20 times less than equivalent sensors today), and can detect both gamma and neutron radiation, the unique signatures of radiological and nuclear weapons. A network of such sensors deployed across multiple locations could quickly determine if an anomalous reading indicated a potential threat and provide the foundation for a critical layer of defense against weapons of mass terror.

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.

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. And 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.

Mastering the Information Explosion

The accelerating growth of digital data, and the Nation's increasing reliance on information systems in every sector of society, present a challenge and an opportunity. The opportunity is to derive from this massive trove the myriad associations and causalities that, once unveiled, can provide insights into everything from the predicted arrival of a new strain of influenza to the plans for a terror attack halfway around the globe. The challenge is how to separate these valuable signals from noise, and how to be able to trust the information and information systems upon which we now rely for virtually every function.

DARPA is developing novel approaches to deriving insights from a wide variety of datasets, and is developing technologies to ensure that the data and systems with which critical decisions are made are trustworthy.

Adoption and impact

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).

Language Translation and Analysis

DARPA has a long and storied history of breakthroughs in voice recognition, translation and language processing, including seminal contributions to the technology that eventually became Siri. More recently, a number of DARPA's language programs have transitioned to the military Services and other outlets where they are making a difference, including:

The Broad Operational Language Translation (BOLT) program aimed to enable communication with non-English-speaking populations and identify important foreign-language information by allowing English-speakers to understand foreign-language sources of all genres, including chat, messaging and informal conversation and providing English-speakers the ability to quickly identify targeted

information in foreign-language sources using natural-language queries. U.S. Special Operations Command and U.S. Central Command have both actively been using BOLT since some of the program's earliest iterations several years ago. It has also been used extensively in theater, including by U.S. forces in South Korea and by DoD, the National Security Agency and other U.S. Government agencies. Currently, U.S. Army Africa is using it as well.

DARPA's Multilingual Automatic Document Classification, Analysis and Translation (MADCAT) program was launched to develop technologies that can automatically convert foreign language text images into English transcripts, eliminating the need for linguists and analysts while automatically providing relevant, distilled, actionable information to military command and personnel in a timely fashion. It is currently in use by the Defense Language Institute and with U.S. Forces Korea.

The Rapid Automatic Transcription of Speech (RATS) program was designed to create algorithms and software for determining whether a communications signal includes speech or is just background noise or music, identifying the language being spoken and whether the speaker is an individual on a list of known speakers, and recognizing specific words or phrases from a list of terms of interest—even when communication channels are extremely noisy and/or highly distorted. RATS is at various stages of testing and transition by the U.S. Air Force, U.S. Navy, Special Operations Command, National Security Agency, Central Intelligence Agency, Federal Bureau of Investigation and Joint Interagency Task Force South.

DARPA's Deep Exploration and Filtering of Text (DEFT) program was designed to use artificial intelligence to enable defense analysts to more efficiently find actionable information in large volumes of documents and to help analysts move from limited, linear processing of huge sets of data to a nuanced, strategic exploration of available information. DEFT technology capable of interpreting human language and converting it to machine-readable knowledge-base entries has been transitioned to the Defense Threat Reduction Agency, the Air Force Research Laboratory, and other activities.

Technical progress

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 machine 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

Cybersecurity for the Grid

Across the United States, some 3,200 separate organizations own and operate electrical infrastructure. The widely dispersed nature of the Nation's electrical grid and associated control systems has a number of advantages, including a reduced risk that any single accident or attack could create a widespread failure from which it might take weeks to recover. Since the late 1990s, however, cost pressures have driven the integration of conventional information technologies into these independent industrial control systems, resulting in a grid that is increasingly vulnerable to cyber attack, either through direct connection to the Internet or via direct 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.

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.

Nurturing the Seeds of Technological Surprise

From its earliest days, DARPA has scoured the research community for new science and engineering insights and invested in programs to reveal radically advanced technological capabilities from those fertile research areas. That tradition holds true 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, significantly 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. And 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.

DARPA's Dialysis-Like Therapeutics (DLT) program is developing a portable device that separates harmful agents from human blood and then returns the cleansed blood to the body in a manner similar to dialysis treatment for kidney failure. The resulting device could remove pathogens from the bloodstream, thereby reducing the morbidity and mortality from infection. DARPA invested in a promising core technology and supported studies that proved its feasibility, which led to the spin-off of a new biotechnology company that is now using venture funding to scale up and file for FDA medical device approval.

Technical progress

Revolutionizing Prosthetics

Over the past year, DARPA has built on previous work in its Revolutionizing Prosthetics program to achieve several new and groundbreaking advances that promise to make a difference for wounded warriors and for countless other people with disabilities. Earlier work developed a sophisticated, modular prosthetic arm that could be easily controlled by the user—a prosthetic that earned Food and Drug Administration approval—and demonstrated the first direct, real-time decoding of neural motor control signals from patients to operate such an arm with near-natural control. A newer focus has been on providing users of prosthetics limbs with a

sense of touch by sending tactile information from mechanical fingertips to the brain. In September, DARPA reported its first success in this domain, when a 28-year-old man who had been paralyzed for more than a decade as a result of a spinal cord injury became the first person to "feel" physical sensations through a prosthetic hand directly connected to his brain. The advance points to a future in which people living with paralysis or missing limbs will not only be able to manipulate objects by sending signals from their brain to robotic devices, but will also be able to sense precisely what those devices are touching.

New Tools to Fight Ebola

The FY 2015 Consolidated and Further Continuing Appropriations Act provided funds for DARPA to pursue technologies relevant to the Ebola outbreak, leveraging platform capabilities in the ADEPT program that aims to outpace infectious diseases. As a result of that additional support, DARPA was able to achieve a number of milestones in quick order, including completion of a study showing that a novel DNA-based vaccine could protect non-human primates against a lethal Ebola challenge, completion of a Phase I human safety trial for a DNA-based vaccine, identification of highly protective antibodies retrieved from U.S. Ebola survivors, commencement of manufacture of a protective Ebola antibody, and successful demonstration of potentially therapeutic levels of DNA-encoded Ebola antibodies in small animals.

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 measurement 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 10^{18}, 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

Neural Engineering Systems Design

The science fiction dream of linking the brain directly to the outside world has in recent years started becoming a reality—initially through the development of implantable medical devices such as deep brain stimulators used today to treat Parkinson's disease and other conditions and, more recently, through work by DARPA and others to develop brain-machine interfaces that allow amputees and people living with paralysis to operate robotic prosthetic arms and hands with their

thoughts. Even state-of-the-art brain-machine interfaces, however, have relatively small capacities compared to the enormous computing power of today's digital systems and of the brain itself—a situation that has been likened to two supercomputers trying to talk to each other through an old 300-baud modem.

DARPA's Neural Engineering System Design (NESD) program stands to dramatically enhance research capabilities in neurotechnology and provide a foundation for new therapies and other capabilities by developing small, implantable systems that can communicate clearly and individually with any of up to one million neurons in a given region of the brain. In addition to that hardware challenge, NESD aims to develop the advanced mathematical and neuro-computation techniques to transcode high-definition sensory information between two contrasting languages—the brain's cortical neuronal representations and the ones and zeros of electronic systems—and then compress and represent those data with minimal loss of fidelity and functionality.

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

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. 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 FY 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 FY 2017 budget request for DARPA is $2.973 billion. This amount is the same as that requested for FY 2016 and $105 million more than the $2.868 billion appropriated for FY 2016. To put these numbers in context, from FY 2009 to FY 2013 DARPA's budget eroded significantly through a series of reductions, including the 8 percent across-the-board sequestration cut in FY 2013. The total reduction to DARPA's budget from FY 2009 to FY 2013 was 20 percent in real terms. With modest increases in FY 2014 and 2015 and a slight decrease for FY 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 FY 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, and—in its most recently created technical office—biological 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. And 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. So I will close this testimony where I started, thanking you for your support and your trust. Both are vital to achieving our mission. I will be pleased to respond to your questions.

Arati Prabhakar
Director, Defense Advanced Research Projects Agency

Arati Prabhakar is the director of the Defense Advanced Research Projects Agency.

Dr. Prabhakar has spent her career investing in world-class engineers and scientists to create new technologies and businesses. Her first service to national security started in 1986 when she joined DARPA as a program manager. She initiated and managed programs in advanced semiconductor technology and flexible manufacturing, as well as demonstration projects to insert new semiconductor technologies into military systems. As the founding director of DARPA's Microelectronics Technology Office, she led a team of program managers whose efforts spanned these areas, as well as optoelectronics, infrared imaging and nanoelectronics.

In 1993, President William Clinton appointed Dr. Prabhakar director of the National Institute of Standards and Technology, where she led the 3,000-person organization in its work with companies across multiple industries.

Dr. Prabhakar moved to Silicon Valley in 1997, first as chief technology officer and senior vice president at Raychem, and later vice president and then president of Interval Research. From 2001 to 2011, she was a partner with U.S. Venture Partners, an early-stage venture capital firm. Dr. Prabhakar identified and served as a director for startup companies with the promise of significant growth. She worked with entrepreneurs in energy and efficiency technologies, components for consumer electronics, and semiconductor process and design technology.

Dr. Prabhakar received her Doctor of Philosophy in applied physics and Master of Science in electrical engineering from the California Institute of Technology. She received her Bachelor of Science in electrical engineering from Texas Tech University. She began her career as a Congressional Fellow at the Office of Technology Assessment.

Dr. Prabhakar has served in recent years on the National Academies' Science Technology and Economic Policy Board, the College of Engineering Advisory Board at the University of California, Berkeley, and the red team of DARPA's Defense Sciences Research Council. In addition, she chaired the Efficiency and Renewables Advisory Committee for the U.S. Department of Energy. Dr. Prabhakar is a Fellow of the Institute of Electrical and Electronics Engineers, a Texas Tech Distinguished Engineer, and a Caltech Distinguished Alumna.

QUESTIONS SUBMITTED BY MEMBERS POST HEARING

FEBRUARY 24, 2016

QUESTIONS SUBMITTED BY MR. WILSON

Mr. WILSON. In your opening statement, you mentioned some work on swarming air vehicles. Could you provide some more details on that work so we can understand how that work, and what the Department is thinking about its applications and potential countermeasures?

Mr. WELBY. The Navy is pursuing science and technology efforts in autonomy and unmanned systems for naval operations. In 2015, the Navy demonstrated swarming unmanned aerial vehicles (UAVs) as part of the Low-Cost UAV Swarming Technology (LOCUST) program. The demonstrations are an important step on the way to the 2016 ship-based demonstration of 30 rapidly launched autonomous, swarming UAVs.

The LOCUST program includes a tube-based launcher that can send multiple UAVs into the air in rapid succession. Information-sharing between the UAVs enables autonomous collaborative behavior in either defensive or offensive missions. This autonomous behavior will allow for the UAVs to adapt to changing adversary conditions to include countermeasures. Additionally, with the goal of low-cost, the program aims to "bend the cost curve" in our favor, especially when employed against conventional weapon systems.

Because the launcher and the UAVs themselves have a small footprint, the technology could enable swarms of compact UAVs to be launched from ships, tactical vehicles, aircraft, or other unmanned platforms. Depending on a range of payload options, a wide variety of missions can be enabled ranging from surveillance to strike.

Mr. WILSON. For each of you, how well do your service's science and technology strategies also integrate long-range planning for the facilities, people, and infrastructure needed to support the technical missions of your organizations?

Mr. WELBY. Within the Department, ASD(R&E) continues to provide oversight of the Department's comprehensive S&T investment portfolio through the Reliance 21 framework. Reliance 21 provides a forum to synchronize, coordinate, and deconflict Service and Agency S&T activities. In the last year, we improved joint planning and coordination of S&T activities among the Department's senior S&T leadership to achieve efficiencies and improve the effectiveness of our support to the operating force. This collaborative process captures the interests and activities of the entire R&E enterprise and all our partners in a collection of 17 Communities of Interest (COIs). The COIs maintain awareness of their portfolio areas by reviewing and assessing the alignment of current and planned R&E programs, identifying gaps, and helping to prioritize R&E funding efforts to meet the technical challenges of the DOD in their respective portfolio area. Each Reliance 21 COI represents a specific, cross-domain technology area with a rotating steering group lead, and draws upon subject-matter experts from across the Department working in the relevant technology area. The Reliance 21 framework, its S&T Executive Committee, and technology area COIs are key mechanisms that support ASD(R&E)'s integrated oversight of the Department's S&T investments.

Mr. WILSON. Could you highlight a few areas where the Long Range Research and Development Program for Ground Combat is likely to suggest focusing additional investments?

Ms. MILLER. The Long Range Research and Development Planning Program for Ground Combat (LRRDPP–GC) is an ongoing OSD study that is led by the Assistant Secretary of Defense for Research and Engineering. The LRRDPP–GC is focused on ground combat technologies that can be incorporated into developmental programs over the next five years and acquired and fielded in quantity within 15 years. It assesses capabilities within the following general areas: future conventional combat; future unconventional combat; future urban combat; combat operations conducted with traditional and non-traditional partners; sustaining combat capabilities in highly challenged cyber- and spectrum-denied environments; and future operations on human terrain. Until this study is completed, however, it would be premature to speculate on particular investment recommendations.

Mr. WILSON. For each of you, how well do your service's science and technology strategies also integrate long-range planning for the facilities, people, and infrastructure needed to support the technical missions of your organizations?

Ms. MILLER. The Long-range Investment Requirements Analysis (LIRA) helps Army Science and Technology (S&T) facilitate more informed program planning and budget decisions by looking out over the next 30 years. The LIRA has put additional rigor into the development of the Army's budget submission, creating an environment where the communities who invest in all phases of the materiel lifecycle work together to maximize the Army's capabilities over time and strengthen the ties between the S&T community and their Program Executive Office (PEO), Requirements community, sustainment and installation partners. While the facilities, people, and infrastructure are not currently a significant part of the LIRA process, this planning has allowed the laboratory directors to better understand their long-term needs in these areas. As we move forward with future LIRAs, we will look at further integrating laboratory and research and engineering facilities, people, and infrastructure needs into the process.

Mr. WILSON. For each of you, how well do your service's science and technology strategies also integrate long-range planning for the facilities, people, and infrastructure needed to support the technical missions of your organizations?

Admiral WINTER. The Naval Science and Technology (S&T) Strategy uses a broad investment approach that leverages long-term, targeted basic research and applied research to give talented scientists and engineers in government, academia and industry, the flexibility to pursue new discoveries and promising ideas to support development of new capabilities for the warfighter.

The labs, like other government entities, continue to struggle with competition for highly skilled S&T and support personnel given the salaries and benefits offered by industry and academia. However, workforce planning and development is fairly decentralized so that S&T laboratory directors have sufficient influence on the size and shape of their workforce.

The basic building block for the future workforce is a robust, strategic commitment to Science, Technology, Engineering and Mathematics (STEM) education and talent-development to nurture and sustain a well-educated, highly-experienced and motivated workforce. Through Section 219 of the Duncan Hunter National Defense Authorization Act for Fiscal Year 2009 (Public Law 110–417, 122 STAT. 4356), the Naval Innovative Science & Engineering (NISE) Program makes funds available to Navy laboratories and warfare centers to support in-house workforce efforts. This has been important in expanding the technical capabilities of the STEM workforce, through hands-on work, as well as in providing training and advanced degrees. NISE efforts have provided breakthrough research and have been responsible for maturation and transition of technology to the warfighter and programs of record. NISE has encouraged cross-organizational multi-disciplinary projects that include partnerships with academia and industry.

The aging and deteriorating portions of Navy laboratories and warfare centers threaten their ability to successfully address their mission of discovering and developing future technology. Navy laboratories and warfare centers face the additional challenge of competing with other Military Construction priorities, such as docks for fleet ships, base housing and base hospitals. As technology rapidly advances, laboratory building construction costs continue to grow.

The infrastructure challenges faced by laboratory directors include limited availability of maintenance, repair and construction funding; and reduced capacity of centralized facilities contracting/management functions (also due to limited funding). As a result, our S&T laboratory directors cannot effectively plan for or ensure the long term readiness of S&T facilities and infrastructure. Additionally, our aging facilities and recapitalization challenges also impact our ability to recruit and retain highly skilled S&T and support personnel, mentioned above.

Mr. WILSON. For each of you, how well do your service's science and technology strategies also integrate long-range planning for the facilities, people, and infrastructure needed to support the technical missions of your organizations?

Dr. WALKER. The strategic goals in the Air Force Science and Technology (S&T) Strategy (2014) provide for integrated long-range planning for the people, facilities, and infrastructure necessary to support the Air Force S&T enterprise. Three of the seven strategic goals are specific to these vital areas. All of these strategic goals inform the efforts carried out under the Air Force Research Laboratory's Strategic Plan. Our strategic focus on long-range planning ensures our S&T enterprise can be successful now and into the future.

Mr. WILSON. For each of you, how well do your service's science and technology strategies also integrate long-range planning for the facilities, people, and infrastructure needed to support the technical missions of your organizations?

Dr. PRABHAKAR. Within the Department, ASD(R&E) continues to provide oversight of the Department's comprehensive S&T investment portfolio through the Reliance 21 framework. Reliance 21 provides a forum to synchronize, coordinate, and deconflict Service and Agency S&T activities. In the last year, we improved joint planning and coordination of S&T activities among the Department's senior S&T leadership to achieve efficiencies and improve the effectiveness of our support to the operating force. This collaborative process captures the interests and activities of the entire R&E enterprise and all our partners in a collection of 17 Communities of Interest (COIs). The COIs maintain awareness of their portfolio areas by reviewing and assessing the alignment of current and planned R&E programs, identifying gaps, and helping to prioritize R&E funding efforts to meet the technical challenges of the DOD in their respective portfolio area. Each Reliance 21 COI represents a specific, cross-domain technology area with a rotating steering group lead, and draws upon subject-matter experts from across the Department working in the relevant technology area. The Reliance 21 framework, its S&T Executive Committee, and technology area COIs are key mechanisms that support ASD(R&E)'s integrated oversight of the Department's S&T investments.

QUESTIONS SUBMITTED BY MR. LANGEVIN

Mr. LANGEVIN. How you are you working with the Strategic Capabilities Office?

Mr. WELBY. When clearances allow, ASD(R&E) personnel monitor Strategic Capabilities Office (SCO) efforts to avoid the potential for duplication and looks for opportunities to collaborate. To that end, ASD(R&E) personnel currently participate in biweekly SCO enterprise VTCs, and SCO is now partnering with ASD(R&E) on the Small Satellite Communications Network Joint Capability Technology Demonstration initiated in FY 15.

ASD(R&E) personnel periodically brief SCO on relevant technologies when there are opportunities to assist SCO to achieve its objectives. The latest example is an upcoming briefing on hand held link 16-effort.

Mr. LANGEVIN. How do the S&T and intelligence communities work together to drive an informed investment strategy? How are S&T programs prioritized in order to meet threats now, and those in the mid and long-term?

Mr. WELBY. The Science and Technology (S&T) and Intelligence Communities (IC) collaborate through a number of efforts to develop an informed strategy. These efforts include development of an annual Intelligence Needs Plan (INP), routine liaison with a number of individual agencies, and close engagement with the Director of National Intelligence's S&T and weapons-related IC.

The INP is a formal document that provides the IC's, OASD(R&E)'s, and the S&T Executives' intelligence requirements for current programs, as well as intelligence requirements and gaps that need to be filled to begin developing capabilities to mitigate near-term and emerging threats. The value of the INP for the Services and the S&T Communities of Interest is that the INP is the means to ensure that S&T intelligence needs are represented in the IC's planning.

Liaison with various intelligence agencies, through both the Defense Intelligence Officer for S&T and numerous agency liaison and support officers, occurs on a regular basis to inform ongoing S&T efforts and development of longer-range priorities. As an example, ASD(R&E) in collaboration with the acquisition community and the IC, collects data on U.S. and threat systems to identify and assess potential strategic, operational, and tactical vulnerabilities across the near-, mid-, and far-term. The issues identified through these assessments are prioritized based on the expected impact to operational success. These assessments also highlight areas where insufficient information is available on adversaries' capabilities. These intelligence shortfalls are then communicated back to the IC to inform the development of collection requirements through the Intelligence Needs Plan.

Mr. LANGEVIN. How you are you working with the Strategic Capabilities Office?

Ms. MILLER. The Army Acquisition Executive and DASA Research and Technology hold regular meetings with Director, SCO to ensure our efforts are synchronized. Additionally, the SCO directly engages subject matter experts at the Army labs and centers. One example of SCO leveraging current Army S&T investments is with our Extended Range Cannon Artillery (ERCA) effort and subject matter expertise at the US Army Armament Research Development and Engineering Center (ARDEC) to evaluate and demonstrate firing the OSD-funded, Navy-developed Hypervelocity Projectile from an Army powder gun. The SCO is also leveraging Army S&T investments and subject matter expertise at the Aviation and Missile Engineering Research and Development Center (AMRDEC) to evaluate and demonstrate repurposing of existing missile technologies in the area of Fire Support.

Mr. LANGEVIN. How do the S&T and intelligence communities work together to drive an informed investment strategy? How are S&T programs prioritized in order to meet threats now, and those in the mid and long-term?

Ms. MILLER. Understanding the current and projected threat environment is essential as we develop future capabilities and our investment strategy. To this end, we are engaging the National Ground Intelligence Center, the Army G2 and the Office of Technical Intelligence at OSD to remain aware of projected future threats and identify areas of interest for future assessment. Our red teaming/vulnerability analysis activities and our technology wargaming are also fostering closer ties between S&T and the intelligence community while providing insights into potential areas for future investments.

Mr. LANGEVIN. How do the S&T and intelligence communities work together to drive an informed investment strategy? How are S&T programs prioritized in order to meet threats now, and those in the mid and long-term?

Admiral WINTER. The Naval S&T community maintains a robust Science and Technology Intelligence Liaison Officer (STILO) program. These full-time liaison officers are embedded in 25 naval systems commands, warfare centers, laboratories, and university affiliated research centers, ensuring the flow of threat information from intelligence community (IC) to the science and technology (S&T) community. These liaisons also serve to connect intelligence analysts with technical subject matter experts from the Naval S&T community to assist the IC in assessing the maturity and implications of scientific developments by adversaries. Additionally, STILOs have the authority to formally task the IC with intelligence production requirements in support of Naval S&T.

U.S Naval forces require a broad spectrum of core capabilities to assure access to the global maritime domain. Consequently, the Naval Science and Technology (S&T) strategy invests in a balanced and broad portfolio of promising scientific research and innovative technology in the United States and around the world.

Science and technology investment balance, to address near-term and mid-to-long-term priorities, is provided by the Navy S&T Strategy and guidance from the Navy Research, Development, Test & Evaluation (RDT&E) Corporate Board. There are four components of the investment portfolio.

- Discovery and Invention (D&I) makes up 50% of the portfolio and includes basic research (6.1) and early applied research (6.2) to address long term priorities.
- Leap-Ahead Innovations make up 12% of the portfolio and includes Innovative Naval Prototypes and the majority of SwampWorks efforts. This component of the technology portfolio defines the future of naval warfighting.
- Technology Maturation makes up 30% of the portfolio to deliver critical component technologies to naval acquisition programs. This includes Future Naval Capabilities, which mature in a two- to four-year time frame into products from the late stages of applied research (6.2) and advanced technology development (6.3).
- Quick Reaction makes up 8% of the portfolio by responding to urgent technology needs and solves problems for warfighters in the near-term. This includes funds for TechSolutions, as well as Navy and Marine Corps experimentation.

The Naval S&T strategy is to discover, develop and deliver decisive naval capabilities, near to long term, by investing in a balanced portfolio of breakthrough scientific research, innovative technology and talented people.

Mr. LANGEVIN. How you are you working with the Strategic Capabilities Office?

Dr. WALKER. The Air Force is in dialogue with the Strategic Capabilities Office (SCO) to determine areas where our S&T enterprise can coordinate and leverage SCO efforts. The Air Force also has a liaison position within the SCO to facilitate communication.

Mr. LANGEVIN. How do the S&T and intelligence communities work together to drive an informed investment strategy? How are S&T programs prioritized in order to meet threats now, and those in the mid and long-term?

Dr. WALKER. The Air Force S&T planning process brings together diverse groups of stakeholders to ensure our S&T efforts are well understood and aligned with Air Force priorities. This includes maintaining a robust research component that pushes the technological state of the art across a range of areas for potential military application as well as being responsive to near-, mid-, and far-term technology needs as expressed by the intelligence, operational, and acquisition communities. Air Force S&T planning is integrated into the Air Force's strategy, planning and programming process (SP3) to ensure S&T investments address areas of research and development consistent with time-phased Air Force priorities.

Mr. LANGEVIN. How you are you working with the Strategic Capabilities Office?

Dr. PRABHAKAR. When clearances allow, ASD(R&E) personnel monitor Strategic

Capabilities Office (SCO) efforts to avoid the potential for duplication and looks for opportunities to collaborate. To that end, ASD(R&E) personnel currently participate in bi-weekly SCO enterprise VTCs, and SCO is now partnering with ASD(R&E) on the Small Satellite Communications Network Joint Capability Technology Demonstration initiated in FY 15.

ASD(R&E) personnel periodically brief SCO on relevant technologies when there are opportunities to assist SCO to achieve its objectives. The latest example is an upcoming briefing on hand held link 16-effort.

Mr. LANGEVIN. How do the S&T and intelligence communities work together to drive an informed investment strategy? How are S&T programs prioritized in order to meet threats now, and those in the mid and long-term?

Dr. PRABHAKAR. The Science and Technology (S&T) and Intelligence Communities (IC) collaborate through a number of efforts to develop an informed strategy. These efforts include development of an annual Intelligence Needs Plan (INP), routine liaison with a number of individual agencies, and close engagement with the Director of National Intelligence's S&T and weapons-related IC.

The INP is a formal document that provides the IC's, OASD(R&E)'s, and the S&T Executives' intelligence requirements for current programs, as well as intelligence requirements and gaps that need to be filled to begin developing capabilities to mitigate near-term and emerging threats. The value of the INP for the Services and the S&T Communities of Interest is that the INP is the means to ensure that S&T intelligence needs are represented in the IC's planning.

Liaison with various intelligence agencies, through both the Defense Intelligence Officer for S&T and numerous agency liaison and support officers, occurs on a regular basis to inform ongoing S&T efforts and development of longer-range priorities. As an example, ASD(R&E) in collaboration with the acquisition community and the IC, collects data on U.S. and threat systems to identify and assess potential strategic, operational, and tactical vulnerabilities across the near-, mid-, and far-term. The issues identified through these assessments are prioritized based on the expected impact to operational success. These assessments also highlight areas where insufficient information is available on adversaries' capabilities. These intelligence shortfalls are then communicated back to the IC to inform the development of collection requirements through the Intelligence Needs Plan.

QUESTIONS SUBMITTED BY MR. NUGENT

Mr. NUGENT. The Office of Naval Research is conducting groundbreaking research into the dangers of working for prolonged periods of time in extreme high and low pressure environments. I want to give you an opportunity to talk about the innovative solutions being developed under your leadership to prepare our forces for these extreme conditions. Can you describe the extreme pressure conditions these warfighters are operating in? Who in the Navy gets exposed to these conditions? Beyond preparation for a dive, I was amazed to learn that your research is developing treatments for those who suffer adverse effects of prolonged atmospheric pressure in the past. Would you please tell us a little bit about that treatment portion of your work? Is the limitation of your research one of technology or of funding? In other words, could the Warfighter Sustainment program do more to prevent and treat service members exposed to extreme environments with an increase in funding in fiscal year 2017?

Admiral WINTER. The Office of Naval Research (ONR) has a longstanding history of supporting undersea warriors, including Navy Divers, SEALs, and submariners, through the Undersea medicine program, one of the five ONR "National Naval Responsibilities". The missions include deep dives to work on the ocean floor, clandestine transits in cold, dark waters, and long durations in the confines of the submarine. The Undersea Medicine Program comprises the science and technology efforts to overcome human shortfalls in operating in this extreme environment.

One threat faced by both undersea operators and aviators is decompression sickness (DCS), as a result of the body absorbing and releasing nitrogen and other gases with changing atmospheric pressure. Research is underway to better understand the causes of DCS and to develop pharmaceutical interventions to prevent and treat DCS. A theory that has derived from ONR supported research is that the extreme pressures cause small pieces of our body's cells called microparticles to break off and enter the blood stream. These microparticles are thought to act as a nucleus for the formation of gas bubbles. This finding lends itself to further research to understand how microparticles can be effectively treated. The program is also supporting development of injectable substances that can absorb the extra gases in the blood stream.

The high pressures also affect the way the body responds to oxygen. Oxygen toxicity seizures and lung damage can occur when operators are exposed to abnormally high levels of oxygen while, for example, using a clandestine rebreather to avoid a bubble trail. Undersea Medicine is exploring the repurposing of FDA-approved epilepsy and asthma drugs to treat these conditions. Recent findings with an animal model have demonstrated that a high-fat dietary supplement can delay the onset of oxygen toxicity seizures and are now moving to human testing.

Conversely, hypoxia, the condition when the body can't acquire enough oxygen is a concern with breathing equipment use, high-altitude mountain operations, and casualty evacuations. A "Hypoxia Alert and Mitigation System" is under development for aviators and medical personnel to prevent and treat hypoxia.

Undersea Medicine is also addressing the increased operational focus being placed on undersea clandestine operations. Undersea Human Performance efforts apply advancements in the understanding of the human mind and body to the areas of human-systems integration, underwater situational awareness, and maintaining physical and cognitive readiness. For the first time, researchers from Navy laboratories are measuring the unique nutritional and metabolic demands of the SEAL Delivery Vehicle operators and will be conducting biometric assessment and performance modeling during cold water training evolutions. Collaboration between Naval Special Warfare and the research community have highlighted nutrition, hydration, respiration and thermal stress as key areas of future investigation.

The Navy supports the President's budget. If additional funds were available, investments could allow groundbreaking new research in genetics, synthetic biology, neuroscience, and physiology to be applied to the undersea domain. Examples of specific areas that could be addressed include understanding how these extreme environmental exposures affect the genes of the operators, analyzing the effects of undersea operations on the gut microbiome, and determining the effectiveness of virtual reality training for underwater missions. Further investments would also enhance the unique Undersea Medicine infrastructure of personnel and facilities in academia, industry and the Navy laboratories.

QUESTIONS SUBMITTED BY MR. CASTRO

Mr. CASTRO. What additional paths do you see aside from ROTC programs, to recruit young men and women into STEM jobs within the Federal Government?

Mr. WELBY. The Department has multiple avenues available to engage with young men and women interested in working with DOD in STEM-related positions. The Science, Mathematics And Research for Transformation (SMART) Scholarship for Service Program provides students pursuing an undergraduate or graduate degree in STEM disciplines the opportunity to receive a full scholarship and employment by the Department upon degree completion. In addition, the Department participates in the Federal-wide Pathways Program, which provides opportunities for internships, recent-graduate hiring, and the Presidential Management Fellows (PMF) program. All three opportunities provide mechanisms for students to engage with the DOD in STEM-related positions that can lead to hiring.

The DOD Labs also have their own programs that may lead to hiring. For example, both the Army and the Navy labs have a science and engineering apprentice program that may lead to a formal hiring arrangement. In addition, the Labs are able to leverage their flexibilities as Science and Technology Reinvention Laboratories (STRLs) to hire through their specific authorities such as Direct Hire Authority, non-competitive transition to full-time positions, and others. In addition to the DOD Labs workforce initiatives, the Human Capital Initiatives (HCI) office within OUSD(AT&L) focuses specifically on the acquisition workforce. Broader workforce initiatives take place in OUSD(P&R).

Finally, for recruitment, the DOD participates in multiple career fairs, college campus recruiting events, and mentorship programs. All of these activities are opportunities for the Department to promote STEM-related positions and directly engage with interested students.

Mr. CASTRO. What additional paths do you see aside from ROTC programs, to recruit young men and women into STEM jobs within the Federal Government?

Ms. MILLER. Hiring a diverse and highly-qualified STEM workforce is critical; however, the harder challenge is ensuring the Army has a STEM-literate workforce not just in STEM jobs but across the entire ecosystem supporting the Warfighter. The Army provides various methods, beyond R.O.T.C., that work to bring in outstanding talent—not just for immediate hiring needs but also for our long-term workforce needs. We use various ways to engage young men and women and introduce opportunities within the Army so that we may attract the right talent that is

uniquely qualified for each requirement. These methods include providing scholarships, mentorship, and unique hands-on experiences; however selecting and recruiting specific personnel for our science and technology laboratories is done directly at the laboratories themselves. This is intentional so as to ensure that our labs have the right people, at the right time and where they are needed so that our labs and researchers are uniquely qualified for their areas of interest and responsibility.

Some of the paths our laboratories use to bring in the right people are the direct hiring authorities that allow us to recruit and bring onboard some of the most highly qualified STEM talent entering the workforce. We also have short term training initiatives that provide existing personnel with the skills to fill jobs and recruit from within. One program that we successfully use is the DOD Science, Mathematics and Research for Transformation (SMART) Scholarship for Service retention program. SMART has proven to be a very successful model to recruit young talent to work for DOD. Additionally, we use research grants to our academic institutions, inclusive of our historically black colleges and universities as well as our minority serving institutions, to work with us on some of our hardest technical challenges. These research investments help introduce young and promising students to the many opportunities available to them within Science & Technology workforce. Lastly we invest in our future researchers and leaders by providing them access to our research facilities and STEM professionals at a young age through the Army Educational Outreach Program (AEOP). AEOP is executed under a cooperative agreement that brings together our Government, industry, and academic partners to provide students access to our laboratories and research centers for STEM enrichment activities, provide one-on-one mentorship opportunities through apprentice programs and reward student achievements in research through competitions, all while introducing students to the world of DOD research. One of the main objectives of AEOP is to build the diverse and highly qualified talent pool for which our work depends.

Mr. CASTRO. What additional paths do you see aside from ROTC programs, to recruit young men and women into STEM jobs within the Federal Government?

Admiral WINTER. In addition to science, technology, engineering, and mathematics (STEM) opportunities available through the Navy Reserve Officers Training Corps (ROTC), the U.S. Naval Academy and other programs leading to a commission in the officer corps, there are numerous enlisted ratings offered through Navy Recruiting Command, focusing on STEM-related occupations.

To attract, recruit, develop, and retain bright, talented young men and women into STEM fields within the civilian workforce, the Department of the Navy (DON) administers and participates in a number of programs overseen by the Office of Personnel Management (OPM), and managed by the Office of the Secretary of Defense (OSD), the Office of Naval Research (ONR), and the individual naval laboratories and warfare centers.

OPM provided federal agencies the means to solicit and select high school, undergraduate, and graduate students into the Pathways Programs via USAJOBS. The DON participates in the Pathways Internship and Recent Graduates Programs overseen by the Department of Defense (DoD) per the memorandum of understanding with OPM. While the Pathways Programs have served as a pipeline, they have presented some challenges. Hence, we are anxiously awaiting the publication of the federal register update that will allow the implementation of National Defense Authorization Act (NDAA) 2015 Section 1105, Temporary Authorities for Certain Positions at Department of Defense Research and Engineering Facilities, and NDAA 2016 Section 1104, Modification to Temporary Authorities for Certain Positions at Department of Defense Research and Engineering Facilities. Section 1105 establishes a pilot program for direct hiring authority for the laboratory directors of specified laboratories for STEM undergraduate or graduate students on a temporary or term basis, for up to three percent of a laboratory's scientific and engineering positions. This authority will provide flexibility for students and for the Navy sponsoring activities to recruit and temporarily employ the "best and brightest." Section 1104 of the NDAA 2016 provides additional flexibility which allows for the non-competitive conversion to permanent appointments upon successful completion of undergraduate and graduate education.

The DON also uses the DOD Science, Mathematics & Research for Transformation (SMART) Scholarship Program, a scholarship-for-service program through which the DOD provides scholarship funds for undergraduate and graduate STEM students at over 200 universities and colleges, including Historically Black Colleges and Universities and other Minority-Serving Institutions (HBCU/MIs). SMART students are mentored by scientists and engineers while working in the DOD laboratories and facilities during the summer months. Students gain valuable experience that often leads to an opportunity for full-time post-graduate employment with those laboratories and facilities.

ONR funds two internship programs, the Science and Engineering Apprenticeship Program (SEAP) for high school students and the Navy Research Enterprise Internship Program (NREIP) for college and graduate students. Both programs offer summer internships that allow students to perform hands-on research alongside Navy scientists and engineers at 36 participating laboratories and warfare centers across the country. In 2015, SEAP funded over 300 high school students for 8-week internships and NREIP funded over 425 undergraduate and 125 graduate students for 10-week internships. These programs offer invaluable real-world STEM research experience as mentors provide meaningful work that fosters the interns' interest in working for the DON upon graduation.

The Naval Research Laboratories and Navy Warfare Centers also benefit from post doctoral candidate fellowships offered through the National Research Council and American Society of Engineering Education (NRC and ASEE). These one-to-two-year appointments allow recent Ph.D. graduates invaluable opportunities to perform research at our laboratories. These opportunities, coupled with the direct hire authority enacted by Congress for advanced degrees, will enable us to hire researchers with skills and interests that align with DON needs.

This continuum of programs was strategically designed to attract, recruit, and develop students from across the education spectrum. We must remain pro-active in these efforts. Therefore, we continually assess the performance of each of these programs and the quality of the students we are attracting, to ensure the programs and students meet the current and long-term STEM workforce requirements.

Mr. CASTRO. How does the Air Force STEM Outreach Office work to attract more minorities and women into STEM?

Dr. WALKER. In FY15, targeted programs impacted over 11,000 children from underrepresented schools. Also in FY15, we impacted over 1,700 female students through programs specifically targeting this audience. The Air Force conducts 2000+ STEM outreach events per year, leveraging local, state and federal organizations to reach 200,000 students and teachers across the United States, mostly concentrated around 29 Air Force installations.

In FY16, our base-level K–12 STEM programs have planned over 180 activities targeted to underrepresented groups. We have also undertaken an initiative to find more ways to coordinate with the AF Diversity Office to enhance and increase the effectiveness of the programs directed at underrepresented groups. We recently supported the POTUS-sponsored program, My Brothers' Keeper, Week at the Labs, in which our Air Force locations opened our doors to minority children for half-day programs of tours and events.

Mr. CASTRO. What additional paths do you see aside from ROTC programs, to recruit young men and women into STEM jobs within the Federal Government?

Dr. WALKER. One path the Air Force uses is the scholarship for service Science, Mathematics And Research for Transformation (SMART) Program. Over the past 9 years, the Air Force has sponsored 640 scholars in the SMART Program. There are 337 individuals that have completed their service commitment and 87 percent of them continue to work for the Air Force. The Air Force also has numerous internship programs that are used to attract and recruit STEM talent to an Air Force career.

Mr. CASTRO. What additional paths do you see aside from ROTC programs, to recruit young men and women into STEM jobs within the Federal Government?

Dr. PRABHAKAR. The Department has multiple avenues available to engage with young men and women interested in working with DOD in STEM-related positions. The Science, Mathematics And Research for Transformation (SMART) Scholarship for Service Program provides students pursuing an undergraduate or graduate degree in STEM disciplines the opportunity to receive a full scholarship and employment by the Department upon degree completion. In addition, the Department participates in the Federal-wide Pathways Program, which provides opportunities for internships, recent-graduate hiring, and the Presidential Management Fellows (PMF) program. All three opportunities provide mechanisms for students to engage with the DOD in STEM-related positions that can lead to hiring.

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