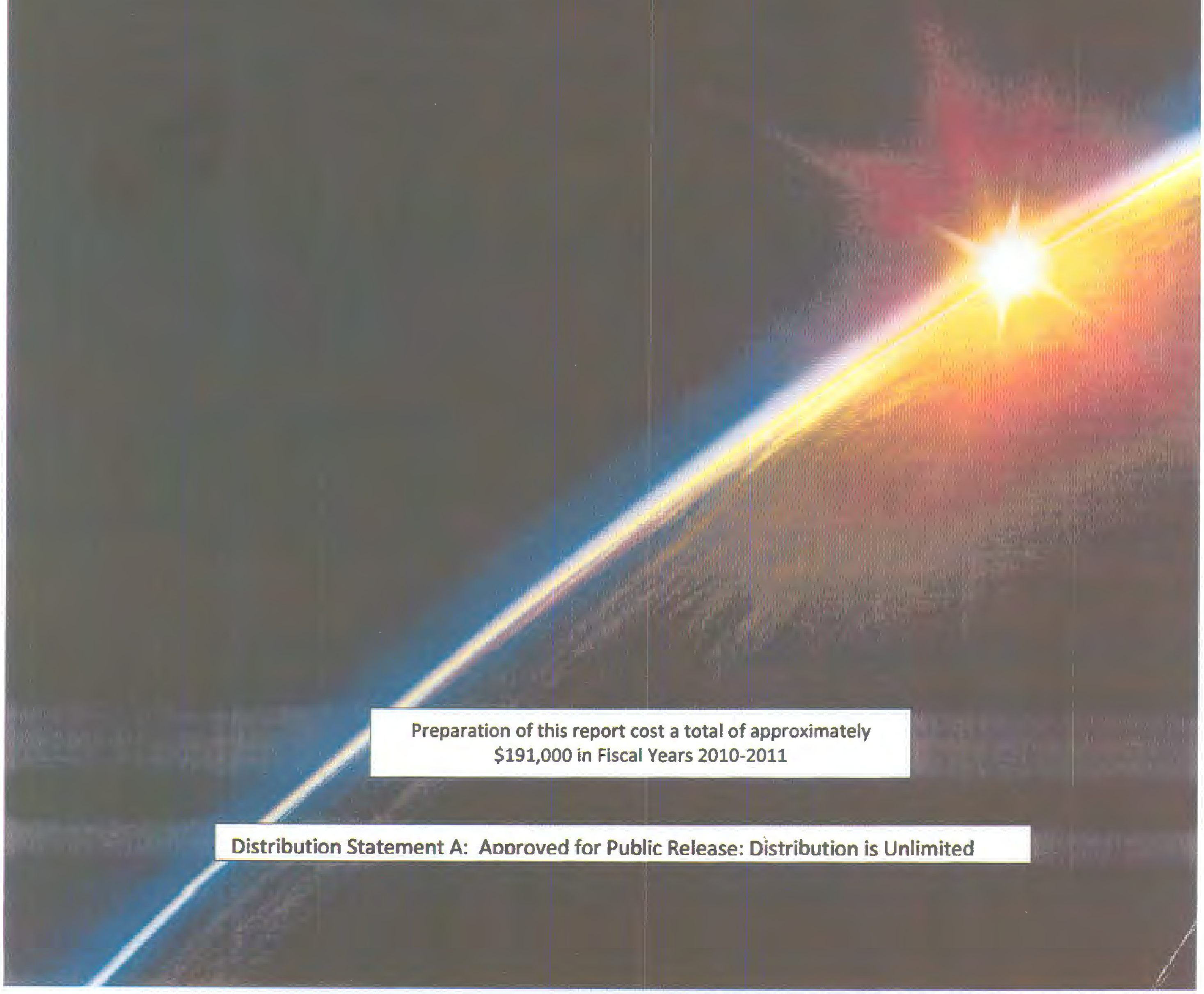
DEPARTMENT OF DEFENSE SPACE SCIENCE AND TECHNOLOGY STRATEGY

2011



Preparation of this report cost a total of approximately
$191,000 in Fiscal Years 2010-2011

Sec 2272 Title 10 USC Space Science and Technology Strategy as amended by NDAA 2010 Sec. 911

§ 2272. Space science and technology strategy: coordination

(a) Space Science and Technology Strategy.—

(1) The Secretary of Defense and the Director of National Intelligence shall jointly develop and implement a space science and technology strategy and shall review and, as appropriate, revise the strategy annually. Functions of the Secretary under this subsection shall be carried out jointly by the Director of Defense Research and Engineering and the official of the Department of Defense designated as the Department of Defense Executive Agent for Space.

(2) REQUIREMENTS. The strategy under paragraph (1) shall, at a minimum, address the following issues:

(A) Short-term and long-term goals of the space science and technology programs of the Department of Defense.

(B) The process for achieving the goals identified under subparagraph (A), including an implementation plan for achieving those goals.

(C) The process for assessing progress made toward achieving those goals.

(D)The process for transitioning space science and technology programs to new or existing space acquisition programs.

(3) The strategy under paragraph (1) shall be included as part of the annual National Security Space Plan developed pursuant to Department of Defense regulations and shall be provided to Department of Defense components and science and technology entities of the Department of Defense to support the planning, programming, and budgeting processes of the Department.

(4) The strategy under paragraph (1) shall be developed in consultation with the directors of research laboratories of the Department of Defense, the directors of the other Department of Defense research components, and the heads of other organizations of the Department of Defense as identified by the Director of Defense Research and Engineering and the Department of Defense Executive Agent for Space.

(5) The Secretary of Defense and the Director of National Intelligence shall biennially submit the strategy developed under paragraph (1) to the congressional defense committee every other year on the date on which the President submits to Congress the budget for the next fiscal year under section 1105 of title 31.

(b) Required Coordination.— In carrying out the space science and technology strategy developed under subsection (a), the directors of the research laboratories of the Department of Defense, the directors of the other Department of Defense research components, and the heads of all other appropriate organizations identified jointly by the Director of Defense Research and Engineering and the Department of Defense Executive Agent for Space shall each—

(1) Identify research projects in support of that strategy that contribute directly and uniquely to the development of space technology; and

(2) Inform the Director of Defense Research and Engineering and the Department of Defense Executive Agent for Space of the planned budget and planned schedule for executing those projects.

(c) Definitions.— In this section:

(1) The term "research laboratory of the Department of Defense" means any of the following:

(A) The Air Force Research Laboratory.

(B) The Naval Research Laboratory.

(C) The Office of Naval Research.

(D) The Army Research Laboratory.

(2) The term "other Department of Defense research component" means either of the following:

(A) The Defense Advanced Research Projects Agency.

(B) The National Reconnaissance Office.

(6) INITIAL REPORT.—The first space science and technology strategy required to be submitted under paragraph (5) of section 2272(a) of title 10, United States Code, as amended by paragraph
(3) of this subsection, shall be submitted on the date on which the President submits to Congress the budget for fiscal year 2012 under section 1105 of title 31, United States Code.

(b) GOVERNMENT ACCOUNTABILITY OFFICE REVIEW OF STRATEGY.—

(1) REVIEW.—The Comptroller General shall review and assess the first space science and technology strategy submitted under paragraph (5) of section 2272(a) of title 10, United States
Code, as amended by subsection (a)(3) of this section, and the effectiveness of the coordination process required under section 2272(b) of such title.

(2) REPORT.—Not later than 90 days after the date on which the Secretary of Defense and the Director of National Intelligence submit the first space science and technology strategy required to be submitted under paragraph (5) of section 2272(a) of title 10, United States Code, as amended by subsection (a)(3) of this section, the Comptroller General shall submit to the congressional defense committees a report containing the findings and assessment under paragraph (1).

We will continue to pursue, adapt, and evolve the unique technologies, innovative exploitation techniques, and diverse applications that give the United States its strategic advantage in space. The United States seeks to maintain and enhance access to those global and domestic technologies needed for national security space systems. We will do so by expanding technology partnerships with the academic community, industry, U.S. and partner governments, mission customers, and other centers of technical excellence and innovation, consistent with U.S. policy, technology transfer objectives, and international commitments. To advance the science and technology that enables U.S. space capabilities, we will continue to assess global technology trends to find emerging technologies and potential breakthroughs. We will explore new applications of current technologies and the development of unique, innovative technologies and capabilities. We will improve the transition of scientific research and technology development to the operational user and into major system acquisition. To the extent practicable, we will also facilitate the incorporation of these capabilities and technologies into appropriate domestic space programs.

– National Security Space Strategy

Introduction

The DoD Space Science and Technology (S&T) Strategy guides the development of the space-unique technologies that are essential to maintain existing U.S. conventional and asymmetric military advantages enabled by space systems at the strategic, operational, and tactical levels. The U.S. Space Policy, National Security Strategy (NSS), Quadrennial Defense Review (QDR), National Security Space Strategy (NSSS), and Defense S&T Strategy provide the strategic foundation for the DoD Space S&T Strategy. The Strategy is further informed by warfighter and Intelligence Community identified needs as expressed through integrated priority lists, joint user operational need statements, current limitations in information collection and processing means, and identified future capability needs.

This strong foundation guides evaluations to determine: (1) which can be satisfied through modification of existing tactics, techniques, and procedures; (2) which can be satisfied through existing programs of record; and finally (3) those that can only be satisfied through the development of new capabilities. The DoD Space S&T Strategy focuses on providing those new capabilities through the development and maturation of technologies that will address unsatisfied needs, reduce risk in major acquisition programs, maintain technological superiority over potential adversaries, enable international cooperation, leverage commercial capabilities, avoid technological surprise, assist in maintaining a healthy and competitive industrial base, and mitigate vulnerabilities of space systems. The Strategy also supports critical themes from the NSSS of increased resilience, foreign cooperation, and hosted payloads.

Space S&T, enabling new and improved space systems that meet these important challenges to our nation, will be performed in an environment that promotes cooperation, collaboration, and partnership among all S&T organizations, including foreign and commercial entities. A rigorous, comprehensive space S&T program, consistent with economic trends and budgetary constraints, ensures that the United States will continue to possess the distinctive advantages that space provides the DoD and the IC combat support agencies.

Methodology

This strategy has been prepared by the Assistant Secretary of Defense for Research and Engineering (ASD(R&E) - formerly the Director, Defense Research & Engineering) and the DoD Executive Agent (EA) for Space with the participation of space S&T organizations within the Defense Components, the Directors of the appropriate research laboratories, as well as the National Reconnaissance Office (NRO). Additionally, the Office of the Director of National Intelligence provided advice and assistance.

Senior Executives, General and Flag Officers, and senior technologists from the various organizations participated in this collaborative process. They identified short- and long-term goals, processes for achieving those goals, methodologies to assess and monitor progress, and approaches to transition technologies to new or existing space acquisition programs.

Short- & Long-Term Space S&T Goals

The National Security Space Strategy describes the Department's three overarching objectives for national security space: strengthening safety, stability, and security in space; maintaining and enhancing the strategic national security advantages afforded to the United States by space; and energizing the space industrial base that supports U.S. national security. The Department of Defense and Intelligence Community are working to achieve these objectives through five interrelated strategic approaches: promote responsible, peaceful, and safe use of space; provide improved U.S. capabilities; partner with responsible nations, international organizations, and commercial firms; prevent and deter aggression against space infrastructure that supports U.S. national security; and prepare to defeat attacks and to operate in a degraded environment. A robust and comprehensive space S&T program that maintains an appropriate balance between short- and long-term goals is paramount to achieving these objectives.

Goals for Satellite Communications (SATCOM)

Short-term S&T goals:

- Communications-on-the-move
- Support to ISR collection platforms
- Dedicated/theater controlled, space-enabled tactical communications

Long-term S&T goals:

- Space-based laser communications for disadvantaged platforms
- V- and W-band radio frequency communications
- Enhanced flexibility and resilience in challenged environments

Goals for Missile Warning, Missile Defense, and Attack Assessment (MW, MD, & AA)

Short-term S&T goals:

- Improved sensors for whole earth staring

- Improved data fusion algorithms for space-based MW, MD, & AA capable sensors
- Improved automated analytic techniques for characterization and discrimination

Long-term S&T goals:
- Reducing the cost of MW, MD, & AA space-based sensing systems
- Fully integrated open architecture ground system for all current and future space-based MW, MD, & AA capable sensors

Goals for Positioning, Navigation, and Timing (PNT)
Short-term S&T goals:
- Improved atomic clocks for space systems
- Initiate update of celestial catalog

Long-term S&T goals:
- Robust alternative space-based navigation capabilities for GPS-denied environments
- Complete update of celestial catalog
- Enhanced and alternative orbital navigation technologies

Goals for Intelligence, Surveillance, and Reconnaissance (ISR)
Short-term S&T goals:
- Increased persistence of space-based ISR
- Enhanced Space Situational Awareness, including data processing
- Improved cross-cueing for space-based assets

Long-term S&T goals:
- Fully integrated space-, air-, and ground-based ISR systems to enhance worldwide persistent coverage
- Advanced tools to integrate data within a common reference framework
- Algorithms to identify activities of critical interest
- Comprehensive knowledge of man-made orbital objects irrespective of size or location

Goals for Space Control (SC)
Short-term S&T goals:
- Improved debris detection, conjunction prediction, mitigation, and potential remediation
- Improved monitoring of potential space-based threats
- Technologies to increase resiliency of space infrastructure
- Technologies to increase cross-domain capabilities to enhance resilience

Long-term S&T goals:
- Achieving the capability to deter, inhibit, delay, or dissuade an adversary from impeding U.S. or Allied nation access to or use of the space domain
- Achieving the capability to maintain mission assurance in a degraded space environment

Goals for Space Access (SA)
Short-term S&T goals:
- Reduce launch cost and cycle time
- More flexible launch operations and improved range safety technologies
- Technologies to expand opportunities to employ commercial space assets synergistically

Long-term S&T goals:
- Enable reduced cost-flexible on-demand launch
- Technologies to enable fully reusable launch systems

Goals for Space Environmental Monitoring (EM)
Short-term S&T goals:
- Improved understanding and awareness of the Earth-to-Sun environment
- Improved space weather forecast capabilities and tools to predict operational impacts
- Improved space weather environmental sensors

Long-term S&T goal:
- Improved space weather forecasting and enabling real-time threat warning

Goals for Command and Control (C2) and Satellite Operations (SATOPS)
Short-term S&T goals:
- Increased autonomy for C2 systems to reduce manning
- Technologies enabling highly efficient on-orbit maneuvers and longer on-orbit life
- Enable multiple simultaneous contacts to reduce logistics tail

Long-term S&T goals:
- Space robotic capabilities with internal decision-making for on-orbit inspection, servicing, repair, assembly, and life-extension
- Fully autonomous systems

Goals for Space Enablers
Short-term S&T goals:
- Standardized and miniaturized components and interfaces for satellite buses and payloads
- Improved tools for design and testing of components and systems
- User-friendly interfaces providing space capabilities for lower-level theater commands
- Technologies to reduce costs and improve performance of satellite buses, payloads, and components
- Improved key building blocks for future responsive space systems
- Disruptive technologies enabling transformational space capabilities (e.g., Carbon-based nanotechnology)

Long-term S&T goals:
- Technologies enabling full autonomy across the spectrum of space system operations
- Generation-after-next component technologies enabling real-time data dissemination of national capabilities to small tactical units
- Ultra-high-efficiency power system components, such as solar cells, batteries, and adaptive point-of-load converters
- Maximize satellite dry mass reduction through game-changing technologies
- Technologies that facilitate integrating U.S. architectures with international and commercial partner systems and technologies

Implementation
The Defense Components implement the DoD Space S&T Strategy as a routine element of their program planning and budgeting procedures. Although each Component employs processes that are specifically tailored to their mission functions and organizational paradigms, all incorporate

the same overarching fundamental elements. Longer-term strategic level goals and objectives are established based on guidance provided by U.S. Space Policy, the NSS, the QDR, the NSSS and the Defense S&T Strategy. Combatant Commander-identified needs, such as those provided by their S&T Integrated Priority Lists, then inform the planning processes to develop more specific program-level goals and objectives. Additionally, insight gained from interchanges with industry, university researchers, allies, and advisory panels assists in identifying additional technology opportunities that may merit pursuit.

The combination of these enables each responsible S&T organization to establish realistic short-term project plans and long-term vectors to guide their technology development activities. In several pervasive technology areas where multiple Components sponsor developmental activities, roadmaps have been employed to document intended short- and long-term goals and to facilitate coordination between sponsoring Components. The Positioning, Navigation, and Timing (PNT) S&T Roadmap, updated approximately every two years, is but one example where Defense Components participate collaboratively in the formulation and execution of space-related S&T projects that ensure U.S. PNT military capabilities remain unrivaled.

Progress metrics and transition plans also are identified as part of the project-level planning process. These provide the timelines, achievement milestones, and intended transitions to system applications that become an integral element of their S&T project investments. In some cases Memoranda of Understanding are employed to provide formal agreements to transition S&T products into either proposed acquisition programs or existing operational systems.

Space-related S&T development activities are performed through a variety of methods. Some projects are conducted within Service laboratories. The Missile Defense Agency (MDA) employs a rapid and cost-effective process utilizing government laboratories in development and industry for production. Other organizations employ contracted efforts awarded in response to Broad Agency Announcements, Small Business Innovation Research solicitations, and Requests for Proposals. Federally Funded Research and Development Centers, University Affiliated Research Centers, under cooperative efforts with other Federal Agencies such as NASA and the Department of Energy, as well as collaborative efforts with other nations also are utilized in the execution of space-related S&T projects.

Assessment

Assessment reviews are conducted at various levels throughout DoD S&T organizations and are typically conducted in a manner consistent with the mission and operating paradigms of the Components. Project and program performance with respect to cost, technical achievements, and schedule progress invariably are evaluated.

Periodic structured and informal programmatic and technical reviews are used to evaluate the effectiveness and quality of space S&T investments and to assess progress toward achievement of objectives and goals. These reviews may include the participation of Combatant Commands, Component headquarters, laboratory directors, peer review boards, and advisory councils. On-going and proposed activities are evaluated to ensure that they are consistent with strategic guidance and identified short- and long-term warfighter needs, while still providing adequate opportunities to explore potentially disruptive or transformational technologies. In select instances, special panels of outside experts may be established to review specific program objectives and technical status for capabilities needed for particular missions.

The Army, for example, employs reviews by the Army Science and Technology Working Group and the Army Science and Technology Advisory Group as part of its internal review process. The Office of Naval Research (ONR) and the Naval Research Laboratory (NRL) conduct annual reviews of applied research and advanced technology development within various portfolios and biennial reviews of basic research. Annually a joint overall Investment Balance Review of the entire Department of the Navy S&T portfolio is performed. For the Air Force, yearly S&T reviews are conducted by the Air Force Space Command Commander (AFSPC/CC), the Air Force Research Laboratory Commander (AFRL/CC), and the Space and Missile Systems Center Commander (SMC/CC); an annual review is also conducted by the Deputy Assistant Secretary of the Air Force (Science, Technology & Engineering). The AFRL/CC conducts quarterly reviews for Space Flagship Capability Concepts.

Within the Defense Advanced Research Projects Agency (DARPA), the high-pay-off, high-risk merits of each project are reviewed through the DARPA Technology Council, consisting of the Directors of the six DARPA Technical Offices and chaired by the Agency Director. Each project establishes technical achievements and milestones to merit continuation. Program managers provide their Office Director informal bi-weekly updates, and the Agency Director and Office Director conduct independent, formal reviews of each program at least once annually.

The MDA review process employs a sequence of disciplined phased reviews. Key principles of the process are: 1) evolutionary delivery of incremental capability to the warfighter; 2) distinct and disciplined phases for Materiel Solution Analysis (concept exploration), Technology Development (concept development), Product Development (design and demonstration), Initial Production, and Production; 3) Balancing capability needs and available resources at the start of product development; and 4) use of Baseline Reviews to validate projects' contributions to the overall program's baselines, approve readiness to transition to the next acquisition phase, and review programs with significant deviations from established baselines.

Within the NRO, biannual briefings to senior management confirm strategic direction and shape any programmatic modifications required as a result of program cancellations, changes in S&T funding, or revised technology need dates for acquisition systems. The Advanced Systems and Technology (AS&T) Directorate conducts internal monthly reviews, as well as quarterly reviews with SMC that facilitate transition and insertion of advanced technologies, such as radiation-hardened electronics, into acquisition programs.

In addition to the reviews employed within the Components, the ASD(R&E), in conjunction with the S&T Executive Council, conducts an annual review of all DoD S&T investments. Warfighter Technical Councils and Acquisition Program Executive Office reviews also may be conducted when appropriate. Space-related Advanced Technology Demonstrations (ATD) are reviewed yearly at the Applied Technology Council held as part of the Space S&T Council.

Transition

Planning for transition is an integral part of the DoD Space S&T Strategy. Although space S&T programs have some unique attributes compared to other types of S&T efforts, there is no single distinctive process for transitioning space S&T products. Instead, transition processes are tailored to the nature of the technology being developed and ultimate application.

For a wide variety of component technologies, such as radiation hardened micro-electronics, solar cells, electric thrusters, and batteries, the S&T projects develop the next generation of components and conduct the necessary ground-based or space-based testing to verify performance and suitability. Once this set of activities has been completed the component is then available as an "off-the-shelf item," which the vendor can then bid in response to solicitations from prime or lower-tier contractors.

Joint Capability Technology Demonstrations (JCTD) provide another approach to assess innovative technologically mature capabilities and determine military utility that can facilitate transitioning to operational status. JCTD emphasis is on technology integration and assessment rather than technology development. JCTD demonstrations are jointly sponsored by operational users and the material development communities.

Some technology programs are focused on obtaining critical phenomenological data typically acquired from space experiments, such as the Mid-course Space eXperiment (MSX) and its more recent follow-on, the Near Field Infrared Experiment (NFIRE). Algorithms, analysis techniques, and models created using such data are transitioned into acquisition activities by the government and industry specialists and designers in those programs.

Proof-of- principle or proof-of-concept demonstrations provide another tool for transition. After completion of the baseline mission, the MSX Space Based Visible (SBV) sensor was employed to demonstrate tracking of objects in geostationary orbit. This Advanced Concept Technology Demonstration subsequently transitioned SBV to become an operational augmentation sensor for space situational awareness for a number of years.

The more recent Communications/Navigation Outage Forecast System (C/NOFS) provides a similar example. In 2010, C/NOFS transitioned to the AF/SMC Defense Meteorological Systems Group to continue to provide data to the Weather Center for operational forecasting.

Some technologies must be demonstrated in the actual space environment to verify and validate performance to support transition. The DoD Space Test Program (STP), created in 1965, supports on-orbit test and experimentation for those organizations not otherwise authorized for space flight. As of September 2010, STP has provided space flight for 206 missions hosting 494 experiments. Many of those experiments have laid the groundwork for operational military space systems such as GPS, Milstar, and DMSP. Most recently, STP was instrumental in providing spaceflight of the AFRL TacSat-3 to provide tactical hyperspectral imagery.

The Operationally Responsive Space (ORS) program is developing new approaches for rapid transition of space technologies from the laboratory to warfighter capabilities. ORS projects seek to match technologies with concepts innovatively to address specific user identified needs, enable operational experimentation to drive technology maturation, and employ novel approaches to expedite transition into new operational capabilities.

On some occasions, space system acquisition programs have facilitated the transition of new technologies by providing "ride-along" opportunities. These are typically employed to support their technology maturation and risk reduction activities.

Space flight opportunities provided by other U.S. Government agencies, Allied nations, and commercial satellite systems also have been employed to conduct DoD space S&T experiments and demonstrations.

Success Stories

The following are examples of space S&T transition successes within the last five years. The Ballistic Missile Technology program developed and demonstrated Ballistic Missile Range Safety Technology to provide modern telemetry, GPS metric tracking, and command destruct capabilities to space range users in a portable and rapidly reconfigurable system. The system was successfully tested at the operational launch facilities based on the system's ability to support a broader spectrum of missions beyond ballistic test, including human space flight, space lift, and flight test. AFSPC renamed the operational system as the "Transportable Command and Telemetry System."

The C/NOFS satellite was launched in 2008 by STP. The C/NOFS program, developed and executed by AFRL, included a dedicated equatorial satellite to measure the properties of the ionosphere; a network of ground-based sensors to measure scintillation and space-to-ground total electron content; and a data center that assimilates the data from the satellite and ground sensors into models of the ionosphere, forecasts the state of the ionosphere, and assesses which regions of the ionosphere are likely to cause scintillation problems. Also included is a suite of products that provide real-time situational awareness to warfighters regarding the effects of space weather on communications/navigation systems. In 2010, the system was transitioned to operational use. C/NOFS also serves as a possible model for the next generation of space weather capabilities.

TacSat-3 (Joint Warfighting Space Demonstrator), launched in 2009, was developed cooperatively by an AFRL-led team that included the Naval Research Laboratory, Army Space and Missile Defense Command, and SMC. It demonstrated hyperspectral imaging products in rapid response to target detection and identification by tactical warfighters, a plug-and-play experimental payload, rapid launch and deployment, and responsive theater communications, delivering "decision quality" information to operational and tactical users in near-real-time. TacSat-3 transitioned to Air Force Space Command for operational use in 2010.

NFIRE, launched in 2007, performed missile phenomenology data collection as a key component of MDA's kinetic energy ICBM boost phase intercept research program. NFIRE gathered near-field, high, and low-resolution images of a boosting rocket to improve understanding of missile exhaust plume observations and plume-to-rocket body discrimination. NFIRE also supported assessment of the viability of laser communications for missile defense, including laser cross-links between satellites to transmit missile tracking information faster over longer distances.

Hyperspectral Imager for Coastal Ocean (HICO)/Remote Atmospheric and Ionospheric Detection System (RAIDS) Experiment Pallet, an ONR-sponsored NRL experiment, was a cooperative DoD STP effort with the Japanese Space Agency and NASA. HICO operates at visible and near-infrared wavelengths to detect, identify, and quantify coastal geophysical features. RAIDS performs global remote sensing of Earth's thermosphere and ionosphere and calibration for LEO observations. It was launched and installed on the International Space Station in 2009 and provided hyperspectral littoral imaging in support of U.S. Haiti relief efforts.

ACKNOWLEDGEMENTS

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Department of Defense

- Office of the Secretary of Defense
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  - Under Secretary of Defense for Intelligence
  - Space & Intelligence Office, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics

- Defense Components
  - Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology
  - Army Space and Missile and Defense Command
  - Office of Naval Research
  - Naval Research Laboratory
  - Office of the Assistant Secretary of the Air Force for Acquisition
  - Air Force Research Laboratory
  - Defense Advanced Research Projects Agency
  - National Reconnaissance Office
  - Missile Defense Agency
  - National Geospatial-Intelligence Agency

Other Government Organizations

- Director of National Intelligence
- Central Intelligence Agency
- Department of Energy

CORE SPACE CAPABILITIES

Source: National Security Space Plan – 3 May 2010

Satellite Communications (SATCOM) - Provides a seamless, end-to-end, space-based communications (both government owned and leased) system of systems, that is integrated and interoperable both internally and externally.

Missile Warning and Attack Assessment (MW&AA) – Timely and unambiguous detection, from space, of ballistic missile launches and nuclear detonations.

Positioning, Navigation and Timing (PNT) - Generating and using signals to enable determination of precise location, movement, orientation, and time.

Intelligence, Surveillance and Reconnaissance (ISR) - Space-based systems that collect Geospatial & Signals Intelligence; includes National Technical Means, Commercial/Foreign Family of Systems, and small, rapid-response opportunities, and space situational awareness.

Space Control (SC) - Provides freedom of action in space for friendly forces.

Space Access (SA) - Delivery, maneuvering, and recovery of payloads to and from space in a responsive, reliable, flexible manner, thereby ensuring assured access to space in peace, crisis, and through the spectrum of conflict.

Space Environmental Monitoring (EM) - Remote sensing and in-situ monitoring of the extended operational environment (near-Earth space), helio-space, and high energy space to accurately specify and forecast conditions using derived data.

Command and Control (C2) - Provides for the exercise of authority over assigned and attached space forces and resources to monitor, assess, plan, and execute space operations at all echelons of command.

Satellite Operations (SATOPS) - Operations conducted to maneuver, configure, operate, and sustain on-orbit National Security Space assets.

DEPARTMENT OF DEFENSE SPACE SCIENCE AND TECHNOLOGY STRATEGY 2013

Preparation of this report cost approximately $35,000

Earth image created from Suomi NPP VIIRS sensor data. NOAA National Geophysical Data Center

Sec 2272 Title 10 USC Space Science and Technology Strategy as amended by NDAA 2010 Sec. 911

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(2) REQUIREMENTS. The strategy under paragraph (1) shall, at a minimum, address the following issues:
(A) Short-term and long-term goals of the space science and technology programs of the Department of Defense.
(B) The process for achieving the goals identified under subparagraph (A), including an implementation plan for achieving those goals.
(C) The process for assessing progress made toward achieving those goals.
(D)The process for transitioning space science and technology programs to new or existing space acquisition programs.
(3) The strategy under paragraph (1) shall be included as part of the annual National Security Space Plan developed pursuant to Department of Defense regulations and shall be provided to Department of Defense components and science and technology entities of the Department of Defense to support the planning, programming, and budgeting processes of the Department.
(4) The strategy under paragraph (1) shall be developed in consultation with the directors of research laboratories of the Department of Defense, the directors of the other Department of Defense research components, and the heads of other organizations of the Department of Defense as identified by the Director of Defense Research and Engineering and the Department of Defense Executive Agent for Space.
(5) The Secretary of Defense and the Director of National Intelligence shall biennially submit the strategy developed under paragraph (1) to the congressional defense committee every other year on the date on which the President submits to Congress the budget for the next fiscal year under section 1105 of title 31.
(b) Required Coordination.— In carrying out the space science and technology strategy developed under subsection (a), the directors of the research laboratories of the Department of Defense, the directors of the other Department of Defense research components, and the heads of all other appropriate organizations identified jointly by the Director of Defense Research and Engineering and the Department of Defense Executive Agent for Space shall each—
(1) Identify research projects in support of that strategy that contribute directly and uniquely to the development of space technology; and
(2) Inform the Director of Defense Research and Engineering and the Department of Defense Executive Agent for Space of the planned budget and planned schedule for executing those projects.
(c) Definitions.— In this section:
(1) The term "research laboratory of the Department of Defense" means any of the following:
(A) The Air Force Research Laboratory.
(B) The Naval Research Laboratory.
(C) The Office of Naval Research.
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(2) The term "other Department of Defense research component" means either of the following:
(A) The Defense Advanced Research Projects Agency.
(B) The National Reconnaissance Office.

Executive Summary

This report provides an update of the Department of Defense (DoD) Space Science and Technology (S&T) Strategy prepared in 2011. Since the preparation of that document a key short-term S&T goal has been accomplished: on-orbit demonstration for communications-on-the-move. Other significant accomplishments since the last report include: on-orbit testing of a prototype whole earth staring sensor, development of multiple sources for whole earth staring focal plane arrays, demonstration of a satellite-to-satellite laser communications crosslink, development of a high performance non-toxic "green" propellant, and successful space-based detection and tracking demonstration for the Aegis Ballistic Missile Defense system.

DoD space S&T organizations collaborate with and leverage the space S&T efforts performed by the Intelligence Community, the National Aeronautics and Space Administration, the Department of Energy, the National Oceanic and Atmospheric Administration, the commercial space industry and, as appropriate, Allied and friendly nations.

Seven new S&T goals have been incorporated into the Strategy. These are: reduce size, weight, power, and cost and improve thermal management for satellite communications; improved star tracker performance; improve/enhance Global Positioning System anti-jam capabilities; expand launch options for space experiments; higher performance on-orbit propulsion; improve capabilities to detect and characterize space objects; and marine meteorology and prediction using space assets. The descriptions for several goals have been modified to more accurately capture the essence of the projects in progress. An Appendix has been included to provide a detailed listing of the specific projects and key metrics supporting the various goals.

The DoD funded projects described in this report are fully consistent with the funding appropriated for DoD space S&T in FY 2012, FY 2013 or in the FY 2014 budget request.

Consistent with the recommendations of the Government Accountability Office this report includes discussion of adequacy of the human capital and infrastructure required to execute this strategy.

> The assessment of potential impacts resulting from sequestration is ongoing and is not reflected in this document.
>
> Impacts on the ability to coordinate activities resulting from recently imposed limitations on travel and conference participation were not known at the time of publication of this document.

We will continue to pursue, adapt, and evolve the unique technologies, innovative exploitation techniques, and diverse applications that give the United States its strategic advantage in space. The United States seeks to maintain and enhance access to those global and domestic technologies needed for national security space systems. We will do so by expanding technology partnerships with the academic community, industry, U.S. and partner governments, mission customers, and other centers of technical excellence and innovation, consistent with U.S. policy, technology transfer objectives, and international commitments. To advance the science and technology that enables U.S. space capabilities, we will continue to assess global technology trends to find emerging technologies and potential breakthroughs. We will explore new applications of current technologies and the development of unique, innovative technologies and capabilities. We will improve the transition of scientific research and technology development to the operational user and into major system acquisition. To the extent practicable, we will also facilitate the incorporation of these capabilities and technologies into appropriate domestic space programs.

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Introduction

The Department of Defense (DoD) Space Science &Technology (S&T) Strategy guides the development of the space-unique technologies that are essential to maintain existing U.S. conventional and asymmetric military advantages enabled by space systems at the strategic, operational, and tactical levels. The U.S. Space Policy, National Security Strategy (NSS), Quadrennial Defense Review (QDR), and the National Security Space Strategy (NSSS) provide the strategic foundation for the DoD Space S&T Strategy. The Strategy is further informed by warfighter and Intelligence Community (IC) identified needs as expressed through integrated priority lists, joint user operational need statements, current limitations in information collection and processing means, and identified future capability needs.

This strong foundation guides evaluations to determine: (1) which can be satisfied through modification of existing tactics, techniques, and procedures; (2) which can be satisfied through existing programs of record; (3) where developments in the commercial sector or performed by other Government agencies can be leveraged to meet DoD needs; and (4) those that can only be satisfied through the development of new capabilities. The DoD Space S&T Strategy focuses on providing those new capabilities through the development and maturation of technologies that will address unsatisfied needs, reduce risk in major acquisition programs, maintain technological superiority over potential adversaries, enable international cooperation, leverage commercial capabilities, avoid technological surprise, assist in maintaining a healthy and competitive industrial base, and mitigate vulnerabilities of space systems. The Strategy also supports critical themes from the NSSS of increased resilience, foreign cooperation, and use of hosted payloads.

DoD Space S&T, enabling new and improved space systems that meet these important challenges to our nation, will be performed in an environment that promotes cooperation, collaboration, and partnership among all U.S. Government funded space S&T organizations, as well as foreign and commercial entities. A rigorous, comprehensive space S&T program, consistent with economic trends and budgetary constraints, ensures that the U.S. will continue to possess the distinctive advantages that space provides the DoD and the IC combat support agencies.

Methodology

This strategy has been prepared by the Office of the Assistant Secretary of Defense for Research and Engineering (OASD(R&E)) with the participation of the DoD Executive Agent for Space staff and the space S&T organizations within the Defense Components with input from the appropriate DoD research laboratories. Additionally, the National Reconnaissance Office (NRO) and the Office of the Director of National Intelligence (ODNI) provided advice and assistance.

Senior representatives and technologists from the DoD Components participated in this collaborative process. Both the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) reviewed the 2011 strategy and provided information on S&T efforts they sponsor relevant to the identified goals. Their input has been incorporated into this update.

The information gathered was employed to update the short- and long-term goals in the 2011 report. One short-term goal was accomplished and has been removed from the goal list. This goal was for maturing the technologies to enable communications-on-the-move for ground forces.

Seven new S&T goals have been incorporated into the Strategy. These are: reduce size, weight, power, and cost and improve thermal management for satellite communications (SATCOM); improved star tracker performance; improve/enhance Global Positioning System (GPS) anti-jam capabilities; expand launch options for space experiments; higher performance on-orbit propulsion; improve capabilities to detect and characterize space objects; and marine meteorology and prediction using space assets.

Additionally, in some cases goals appear as both short- and long-term to reflect that some portion of the capability will be achieved rapidly while the remaining elements require a longer development cycle. The methodologies employed to assess and monitor progress toward achievement of goals, and approaches to transition technologies to new or existing space acquisition programs are discussed in later sections.

Short- & Long-Term Space S&T Goals

The overarching objectives for national security space are: strengthening safety, stability, and security in space; maintaining and enhancing the strategic national security advantages afforded to the U.S. by space; and energizing the space industrial base that supports U.S. national security. The DoD and the IC work together to achieve these objectives through five interrelated strategic approaches: promote responsible, peaceful, and safe use of space; provide improved U.S. capabilities; partner with responsible nations, international organizations, and commercial firms; prevent and deter aggression against space infrastructure that supports U.S. national security; and prepare to defeat attacks and to operate in a degraded environment. A robust and comprehensive space S&T program that maintains an appropriate balance between short- and long-term goals is a key element in achieving these objectives. Goals are presented based on the taxonomies in the Core Space Capabilities (Appendix A). Specific projects supporting the goals below are provided in Tables 1-9 in Appendix B.

Goals for Satellite Communications (SATCOM)

Short-term S&T goals:

- Reduce size, weight, power, cost, and improve thermal management for SATCOM terminals
- Support to intelligence surveillance and reconnaissance (ISR) collection platforms
- Space-based laser communications for disadvantaged platforms and users
- Dedicated/theater controlled, space-enabled tactical communications in contested environments
- Develop/enhance V-, W- and Ka-band radio frequency (RF) communications

Long-term S&T goals:

- Space-based laser communications for disadvantaged platforms
- Develop/enhance V- , W, and Ka-band RF communications
- Enhanced protection and resilience in contested environments

Goals for Missile Warning, Missile Defense, and Attack Assessment (MW, MD, & AA)

Short-term S&T goals:

- Improved sensors for whole earth staring
- Improved data fusion algorithms for space-based MW, MD, & AA capable sensors
- Improved automated analytic techniques for characterization and discrimination

Long-term S&T goals:

- Reducing the cost of MW, MD, & AA space-based sensing systems
- Improved data fusion algorithms for space-based MW, MD, & AA capable sensors
- Fully integrated open architecture ground system for all current and future space-based MW, MD, & AA capable sensors

Goals for Positioning, Navigation, and Timing (PNT)

Short-term S&T goals:

- Improved/enhanced GPS anti-jam capabilities
- Improved atomic clocks for space systems
- Continue update of celestial catalog
- Robust alternative space-based navigation capabilities for GPS-denied environments

- Improved star tracker performance

Long-term S&T goals:

- Robust alternative space-based navigation capabilities for GPS-denied environments
- Complete update of celestial catalog
- Enhanced and alternative orbital navigation technologies

Goals for Intelligence, Surveillance, and Reconnaissance (ISR)

Short-term S&T goals:

- Increased persistence of space-based ISR
- Improved utilization of space assets through cross-cueing, integrated commanding, fusion of data products, and tailored data distribution
- Fully integrated space-, air-, and ground-based ISR systems to enhance worldwide persistent coverage

Long-term S&T goals:

- Fully integrated space-, air-, and ground-based ISR systems to enhance worldwide persistent coverage
- Advanced tools to integrate data within a common reference framework
- Algorithms to identify activities of critical interest

Goals for Space Control (SC) and Space Situational Awareness (SSA)

Short-term S&T goals:

- Improved space object detection, conjunction and drag prediction, mitigation, and potential remediation
- Improved monitoring of potential space-based threats
- Technologies to increase protection and resiliency of space capabilities
- Technologies to increase cross-domain capabilities to enhance resilience
- Enhanced SSA, including data processing
- Improved capabilities to detect and characterize space objects

Long-term S&T goals:

- Achieving the capability to deter, inhibit, delay, or dissuade an adversary from impeding U.S. or Allied nation access to or use of the space domain
- Achieving the capability to maintain mission assurance in a degraded space environment
- Improved monitoring of potential space-based threats
- Comprehensive SSA, including data processing
- Comprehensive knowledge of man-made orbital objects irrespective of size or location
- Enable multiple simultaneous contacts to reduce logistics tail

Goals for Space Access (SA)

Short-term S&T goals:

- Reduce launch cost and cycle time
- More flexible launch operations and improved range safety technologies
- Technologies to expand opportunities to employ commercial space assets synergistically
- Expand launch options for space experiments
- Higher performance on-orbit propulsion

Long-term S&T goals:

- Enable reduced cost-flexible on-demand launch
- Technologies to expand opportunities to employ commercial space assets synergistically
- Technologies to enable fully reusable launch systems

Goals for Space and Terrestrial Environmental Monitoring (EM)

Short-term S&T goals:

- Improved understanding and awareness of the Earth-to-Sun environment
- Improved space environment forecast capabilities and tools to predict operational impacts
  Improved space environmental sensors

Long-term S&T goals:

- Improved space environment forecasting and enabling real-time threat warning
- Marine meteorology and prediction using space assets
- Improved understanding and awareness of the Earth-to-Sun environment

Goals for Command and Control (C2) and Satellite Operations (SATOPS)

Short-term S&T goals:

- Increased autonomy for C2 systems to reduce manning
- Technologies enabling highly efficient on-orbit maneuvers and longer on-orbit life
- Space robotic capabilities with internal decision-making for on-orbit inspection, servicing, repair, assembly, harvesting subsystems, and life-extension

Long-term S&T goals:

- Space robotic capabilities with internal decision-making for on-orbit inspection, servicing, repair, assembly, harvesting subsystems, and life-extension
- Fully autonomous space systems

Goals for Space Enablers

Short-term S&T goals:

- Standardized and miniaturized components and interfaces for satellite buses and payloads
- Technologies to reduce costs and improve performance of satellite buses, payloads, and components
- Improved key building blocks for future responsive space systems
- Disruptive technologies enabling transformational space capabilities such as carbon-based nanotechnology
- Ultra high-efficiency power system components, such as solar cells, batteries, and adaptive point-of-load converters
- Improved tools for design and testing of components and systems
- User-friendly interfaces providing space capabilities for lower-level theater commands

Long-term S&T goals:

- Ultra-high-efficiency power system components, such as solar cells, batteries, and adaptive point-of-load converters
- Maximize satellite dry mass reduction through game-changing technologies
- Technologies that facilitate integrating U.S. architectures with international and commercial partner systems and technologies
- Technologies enabling full autonomy across the spectrum of space system operations
- Generation-after-next component technologies enabling real-time data dissemination of national capabilities to small tactical units

Implementation

The Defense Components implement the DoD Space S&T Strategy as a routine element of their program planning and budgeting procedures. In this, consistent with the management and execution paradigm of Title 10, each Component has the primary responsibility to develop and conduct efforts that address their specific and, at times, unique mission responsibilities.

Thus, even while each Component may employ processes that are specifically tailored to their mission functions and organizational paradigms, all incorporate the same overarching fundamental elements. Longer-term strategic level goals and objectives are established based on guidance provided by U.S. Space Policy, the NSS, the QDR, the NSSS and the Defense S&T Strategy. Combatant Commander-identified needs, such as those provided by their S&T Integrated Priority Lists, inform these planning processes to develop more specific program-level goals and objectives. Additionally, insight gained from interchanges with industry, university researchers, Allies, and advisory panels assists in identifying additional technology shortfalls and opportunities that may merit pursuit.

ASD(R&E), in accordance with DoD Directive 5134.3, retains overall leadership and oversight responsibility for all DoD S&T. These responsibilities include, but are not limited to:

1. Developing the strategies and supporting plans that exploit technology and prototypes to respond to the needs of the Department of Defense and ensure U.S. technological superiority.
2. Conducting analyses and studies; developing policies; providing technical leadership, oversight and advice; making recommendations; and

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issuing guidance for the DoD Research & Engineering (R&E) plans and programs.
3. Recommending approval, modification, or disapproval of programs and projects of the Military Departments and other DoD Components in assigned fields to eliminate unpromising or unnecessarily duplicative programs, and initiation or support of promising ones for R&E.

The combination of these enables each responsible S&T organization to establish realistic short-term project plans and long-term vectors to guide their technology development activities. In technology areas where multiple organizations sponsor activities, interagency coordinating councils, roadmaps, and technical interchanges are employed to facilitate coordination between Components as well as with other federal agencies such as NASA and NOAA.

For example, the Air Force and the Navy provide representatives to the Federal Committee for Meteorological Services and Supporting Research (FCMSSR) chaired by the Office of the Federal Coordinator for Meteorology. Additionally, the Joint Center for Satellite Data Assimilation (JCSDA) is a partnership between NOAA, NASA, the Navy, and the Air Force dedicated to developing and improving the ability to exploit environmental monitoring data for terrestrial weather forecast models and applications.

There are many other mechanisms employed to foster collaboration and coordinate efforts beyond FCMSSR and JCSDA. These include: the NRO Technology Forum; the Joint DoD NASA -U.S. Industry Integrated High Payoff Rocket Propulsion Technology Program; the Joint Army-Navy-NASA-Air Force Inter Agency Propulsion Committee; the Joint Space Team; the Joint NRO-CIA-NOAA-Air Force Space Pillars Meeting; the DoD Space Experiments Review Board; and the NASA/NRO Working Group Meeting.

DoD also continues to aggressively pursue international collaborative efforts with our Allies and other friendly nations. Bi-lateral and multi-lateral agreements enable the DoD space S&T program to pursue collaborative efforts to explore innovative concepts being developed in the international community as well as to benefit from the technical expertise that exists in other countries. In calendar year 2012 alone, two existing collaborative space S&T agreements were extended or augmented and six new ones established.

It is important to note that significant informal coordination and collaboration at the Subject Matter Expert (SME) level occurs between DoD scientists and engineers and their counterparts in other federal agencies, Academia, and the defense and commercial space industry through participation in domestic and international professional conferences. These forums, which enable SMEs to interact on an individual basis, also are critical for advancement of S&T to the mutual benefit of the defense, civil and commercial space sectors.

Progress metrics and transition plans also are identified as part of the project-level planning process. These provide the timelines, achievement milestones, and intended transitions to system applications that become an integral element of their S&T project investments. In some cases Memoranda of Understanding are employed to provide formal agreements to transition S&T products into either proposed acquisition programs or existing operational systems.

Space-related S&T development activities are performed through a variety of methods. Some projects are conducted within Service laboratories. The Defense Advanced Research Projects Agency (DARPA) and the Missile Defense Agency (MDA) employ a variety of methods to execute their space S&T projects. These approaches include, at times, utilizing government laboratories, traditional and non-traditional industry sources under efforts awarded in response to Broad Agency Announcements and other solicitations, Small Business Innovation Research solicitations, sponsorship of Federally Funded Research and Development Centers (FFRDC) and University Affiliated Research Centers (UARC), cooperative efforts with other federal agencies such as NASA and the Department of Energy (DOE), as well as collaborative efforts with Allies and other nations when appropriate.

Assessment

Assessment reviews to measure and monitor progress towards achievement of goals are conducted at various levels throughout DoD S&T organizations. These include working level assessments at the project and program level; reviews at the Component laboratory, organizational and headquarters levels; reviews by independent advisory boards; cross-organizational review forums; and reviews at the Agency Director or Service and DoD Assistant Secretary level. In select cases, the Deputy Secretary of Defense (DSD) may be asked to adjudicate issues that cannot be resolved at lower levels.

These reviews may include the participation of Combatant Commands, Component headquarters, laboratory directors, peer review boards, and advisory councils. On-going and proposed activities are evaluated to ensure that they are consistent with strategic guidance and identified short- and long-term warfighter needs, while still providing adequate opportunities to explore potentially disruptive or transformational technologies. In select instances, special panels of outside experts may be established to review specific program objectives and technical status for capabilities needed for particular missions.

Component level reviews are conducted in a manner consistent with the mission and operating paradigm of each organization. Project and program performance with respect to cost, technical achievements, and schedule progress are evaluated in both periodic structured and informal programmatic and technical reviews.

The Army, for example, employs reviews by the Army Science and Technology Working Group and the Army Science and Technology Advisory Group as part of its internal review process. The Office of Naval Research (ONR) and the Naval Research Laboratory (NRL) conduct annual reviews of applied research and advanced technology development within various portfolios and biennial reviews of basic research. Annually, a joint overall Investment Balance Review of the entire Department of the Navy S&T portfolio is performed.

For the Air Force, yearly S&T reviews are conducted by the Commanders of the Air Force Space Command (AFSPC), the Air Force Research Laboratory (AFRL), and the Air Force Space and Missile Systems Center (AF SMC). The Deputy Assistant Secretary of the Air Force (Science, Technology & Engineering) also conducts a separate annual S&T review. In addition, the Air

Force Office of Scientific Research conducts annual reviews of its basic research portfolio including Space Science, Physics and Astronomy, and Space Propulsion and Power, engaging the public, Government, Industry and Academic scientific and User communities. Finally, the Air Force Scientific Advisory Board (AF SAB) conducts biennial reviews of the AFRL S&T Portfolio, and the Air Force Chief Scientist regularly assesses progress in space S&T.

Warfighter Technical Councils and Acquisition Program Executive Office reviews also may be conducted when appropriate. Space-related Advanced Technology Demonstrations are reviewed yearly at the Applied Technology Council held as part of the Space S&T Council.

To solidify coordination of DoD/DNI space S&T efforts, in January of this year the Deputy Assistant Secretary of Defense (Research) and his counterpart in ODNI, the National Intelligence Manager for Science & Technology, conducted the first of what is expected to be a series of deep-dive review forums. Employing senior SMEs from the DoD and IC space S&T communities, these forums will review DoD and IC funded space S&T efforts in very specific topic areas of common interest. The purpose is to determine if current and planned efforts are sufficient to fulfill the capabilities that will be required in the 2030 timeframe. If shortfalls are identified forum participants will provide recommendations for additional efforts that could be performed to address those gaps. This will enable DoD and DNI to adjust their respective space S&T investment portfolios for those common interest topics.

In addition to the reviews mentioned above, the ASD(R&E), though the Joint S&T Steering Committee, conducts reviews of all DoD S&T investments to strengthen and align S&T efforts across the Department. This review process is structured to ensure all S&T portfolios are reviewed over a two year period. This space S&T strategy will be a guiding document when the space S&T portfolio is reviewed.

When appropriate, Joint S&T Steering Committee recommendations for program or funding adjustments will be submitted for review by the ASD(R&E) Research and Engineering Executive Committee (R&E EXCOM). ASD(R&E) is the R&E EXCOM chair with the Service Acquisition Executives as the principal members. Through cross-component coordination, the R&E EXCOM strengthens the overall effectiveness and efficiency of the department's R&E investments in areas which cannot be addressed adequately by a single component. A primary function of the R&E EXCOM is to conduct deep-dive reviews to enhance S&T program alignment to future acquisition needs.

Finally, the DSD, during the DoD annual program review cycle, may be asked to adjudicate those questions and issues that cannot be resolved in lower level reviews. These issues can include reallocating funding, authorizing major shifts in program focus, approving new initiatives, as well as eliminating efforts that are underperforming or no longer required.

Transition

Planning for transition is an integral part of the DoD Space S&T Strategy. Although space S&T programs have some unique attributes compared to other types of S&T efforts, there is no single distinctive process for transitioning space S&T products. Instead, transition processes are tailored to the nature of the technology being developed and ultimate application.

For a wide variety of component technologies, such as radiation hardened microelectronics, solar cells, electric thrusters, and batteries, the S&T projects develop the next generation of components and conduct the necessary ground-based or space-based testing to verify performance and suitability. Once these activities have been completed, the component is then available as an "off-the-shelf item," which the vendor can then bid in response to solicitations from prime or lower-tier contractors. The development of multiple sources for whole earth staring focal planes arrays typifies this category of activities.

Joint Capability Technology Demonstrations (JCTD) provide another approach to assess innovative technologically mature capabilities and determine military utility that can facilitate transitioning to operational status. JCTD emphasis is on technology integration and assessment rather than technology development. JCTD demonstrations are jointly sponsored by operational users and the materiel development communities.

Some technology programs are focused on obtaining critical phenomenological data typically acquired from space experiments such as the Commercially Hosted IR Payload (CHIRP) experiment and the Near Field Infrared Experiment (NFIRE). Algorithms, analysis techniques, and models created using such data are transitioned into acquisition activities by the government and industry specialists and designers in those programs.

Proof-of-principle or proof-of-concept demonstrations provide another path for transition. The Space Tracking and Surveillance System-Demonstrators (STSS-D) are an excellent example of such activities. During a recent successful demonstration for Aegis Ballistic Missile Defense (BMD) system test STSS-D provided critical detection and tracking data in support of the intercept mission.

Similarly, AFRL's Communications/Navigation Outage Forecast System (C/NOFS) continues to reduce the technical risk for space situational awareness environmental monitoring by validating sensor designs and data exploitation algorithms. The importance of C/NOFS is recognized in the decision to continue to fund orbital operations through satellite end-of-life. C/NOFS data also are being used in the current AFSPC Space-Based Environmental Monitoring (SBEM) Analysis of Alternatives (AoA) to evaluate the military utility of space-based data in assessing the operational impact of equatorial scintillation.

TacSat-4, launched in September 2011, is a joint program sponsored by ONR, the Office of Force Transformation, the Operationally Responsive Space (ORS) Office, and NRL. TacSat-4 successfully demonstrated the ability to provide communications to Marine ground forces on the move. While TacSat-4 continues to be used in experimental operations, it currently is under evaluation by Strategic Command for transition to operational use.

As noted above, some technologies must be demonstrated in the actual space environment to verify and validate performance to support transition. The DoD Space Test Program (STP), created in 1965, supports on-orbit test and experimentation for those organizations not otherwise authorized for space flight. STP has been an essential enabler for integration and launch resources and executing the DoD's Space Experiment Program through providing payload integration, launch, and on-orbit operation services. Through FY12, STP provided space flight for 220 missions hosting 531 experiments. Many of those experiments have laid the groundwork for operational military space systems such as GPS, Milstar, and the Defense Meteorological Satellite Program.

On some occasions, space system acquisition programs have facilitated the transition of new technologies by providing "ride-along" opportunities. These are typically employed to support their technology maturation and risk reduction activities. Space flight opportunities provided by other U.S. Government agencies, Allied nations, and commercial satellite systems also have been employed to conduct DoD space S&T experiments and demonstrations.

Funding

The DoD funded projects included in this strategy represents a program of work fully consistent with the funding appropriated in FY 2012, FY 2013 or in the FY 2014 budget request. This funding is sufficient to pursue the high priority S&T efforts identified by processes including the DoD Combatant Commands Integrated Priority Lists, and S&T Integrated Priority Lists, Joint Urgent Needs and the ASD(R&E) recommendations on S&T priorities to the Secretary of Defense for incorporation in the DoD S&T planning guidance.

Human Capital and Infrastructure

Adequacy of Human Capital and Infrastructure – Air Force:

Every two years, the AF SAB reviews one-half of the portfolio for each of the nine directorates within AFRL and assesses the technical quality, relevance to near-term Air Force needs, potential impact to mid-and far-term Air Force Capabilities and utilization of funding, workforce and facility resources. Space technology development is performed in eight of the nine directorates with the bulk of it within three directorates: AFRL Space Vehicles for satellite technology, AFRL Aerospace Systems for launch vehicle technology, and AFRL Directed Energy for research primarily using ground-based telescopes to support SSA. The ground-based optical space situational awareness and space weather areas have consistently been rated as world-class. The AF SAB has not identified any specific shortfalls in human capital that would detrimentally impact execution of AFRL's current space S&T portfolio.

The AF SAB reviewed the adequacy of AFRL's facilities, determining that the current facilities range from adequate to world class and can meet Air Force S&T needs. As a result of the recent Base Realignment and Closure, AFRL now has a new building to house the space weather team. AFRL also has two facilities capable of fully integrating and testing small experimental satellites. One of these facilities is used primarily for unclassified payloads while the other is for classified payloads. These facilities are also shared with other payload providers from the DOE Sandia National Laboratory. The military construction program also is employed when existing space infrastructure facilities need to be upgraded or when new facilities are required to satisfy emerging needs.

Adequacy of Human Capital and Infrastructure – Navy:

The Navy possesses the necessary personnel and facilities to execute its space S&T program. Based on a comprehensive review of the in-house NRL space research conducted in 2011 an external review team concluded that: (1) the NRL facilities are first-class and comparable to or better than those of any university or NASA center where space science research is performed; and, (2) that state-of-the-art engineering and fabrication facilities are available to support the transition from basic knowledge to mission-oriented programs and the delivery of final products to customers. In addition, NRL has a unique capability to fully integrate, launch, operate, and analyze data from spacecraft representing a valuable, high quality, productive national asset.

Also in 2011, experts from the National Science Foundation, the John Hopkins University Applied Physics Laboratory, and NOAA conducted a review of the ONR Space Program. This review panel concluded that the ONR Space Program: (1) specifically funds important research areas to the Navy that are not being addressed by any other funding agency, (2) significantly and very effectively leverages other funded research efforts that address phenomena relevant for the Navy, and (3) has an integrated and cohesive strategic plan that is being implemented successfully.

Adequacy of Human Capital and Infrastructure – Army:

The Army space S&T program is modest in relation to the efforts performed by the Air Force and the Navy. The Army has determined it has a sufficient cadre of trained personnel to execute its current space S&T programs. However, the Army recognizes it would need to increase staffing levels should its program of work increase substantially.

The Army space S&T program has access to infrastructure and facilities available at Redstone Arsenal, Marshall Space Flight Center, Stennis Space Center, as well as other DoD and DOE laboratories and industry. This network of infrastructure and facilities is more than adequate to enable the Army to execute is current portfolio of space S&T projects.

Adequacy of Human Capital and Infrastructure – DARPA and MDA:

Neither DARPA nor MDA maintain their own laboratory systems. As noted previously, DARPA and MDA execute their space S&T programs through a variety of sources. These sources can include sponsoring programs at the DoD and DOE laboratories, contracts with Industry, efforts performed by Universities and UARCs, placing work with NASA Research Centers or FFRDCs, in cooperative programs with other federal government organizations, and, when appropriate, collaborative projects with Allied and friendly nations. Their execution approach ensures that adequate infrastructure and human capital will be available to support their space S&T efforts.

Success Stories

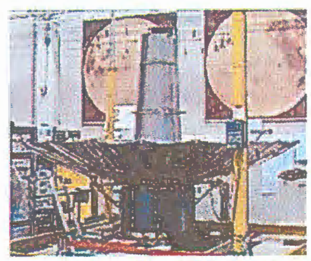
The C/NOFS program includes a dedicated equatorial satellite to measure the properties of the ionosphere; a network of ground-based sensors to measure scintillation and space-to-ground total


Communications/Navigation Outage Forecasting System (C/NOFS)

electron content; and a data center that assimilates the data from the satellite and ground sensors into models of the ionosphere, forecasts the state of the ionosphere, and assesses which regions of the ionosphere are likely to cause scintillation problems. In addition to serving as the pathfinder for space situational awareness environmental monitoring and providing key data for the SBEM AoA, the C/NOFS program is the centerpiece of on-going efforts to develop, validate and transition state-of-the-art forecasting models of the space environment to the Air Force Weather Agency (AFWA), the Joint Space Operations Center (JSpOC), the Global SATCOM Support Center (GSSC), and other operational users. AFRL provides a user-specific scintillation nowcasting product to the GSSC for their use in electro-magnetic interference resolution. C/NOFS has spawned a revolution in the understanding and modeling of the equatorial ionosphere.

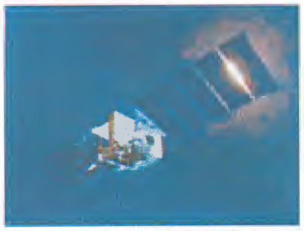
The JSpOC currently monitors tens of thousands of space objects. The number of tracked objects is expected to grow as new sensor systems come completely on line. In 2012 AFRL, under AF SMC sponsorship and the JSpOC Mission Systems (JMS) program, delivered the first increment of a new computer software suite which will satisfy current requirements, including the prediction and avoidance of orbit conjunctions and collisions. JMS Increment 1 provides: a net-centric service oriented infrastructure; a modern, graphical user interface for operating the space fleet; the foundational infrastructure for all future development; and over 80 SSA and command and control applications.

TacSat-4 completed an S&T goal by demonstrating communications-on-the-move capabilities. In addition, TacSat-4 augments geostationary orbit provided SATCOM coverage including High-Latitude Coverage; Friendly Force Tracking/Blue Force Tracking in under-served areas; provides data exfiltration capabilities and flexible up/down channel assignment to improve operations in dense RF and interfered environments; and provides dynamic reallocation to different theatres worldwide.


Tactical Satellite-4 (TacSat-4)

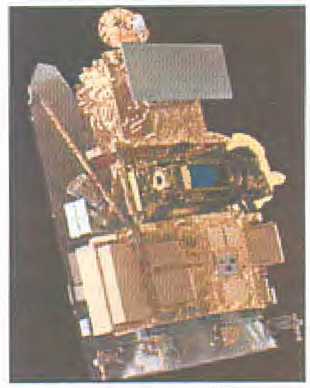
The ONR sponsored Virtual Mission Operations Center (VMOC), developed by NRL, is a web-enabled multi-application service that facilitates requests for secure satellite services by any approved user. Without any man-in-the-loop, user requests are immediately prioritized within VMOC based on the Operational Commander's intent, evaluated for execution based on orbital mechanics and satellite modeling data, and autonomously uploaded into a Satellite Operations Center upload buffer. This new capability dramatically improves utilization as well as speed of command. VMOC, currently being used operationally for the TacSat-4 and ORS-1 satellites, is under evaluation for operational use by other programs.

STSS-D, a pair of low-earth orbit satellites, have achieved a remarkable series of 'firsts' for space-based missile tracking reducing risk for future Ballistic Missile Defense System (BMDS) programs. In numerous MDA collections, the satellites tracked missiles through all phases of flight delivering fire control quality tracks to Aegis destroyers. In addition to precision ballistic


Space Tracking and Surveillance System-Demonstrators (STSS-D)

missile tracking, MDA leverages its unique sensor capabilities to collect data across a broad range of missions including tracking space launches, on-orbit satellites, satellite re-entries, and scientific background and scene data on space and terrestrial environments. STSS-D has conducted over 1,200 collections, an average of seven per day during round-the-clock operations.

NFIRE, a passive, multi-spectral satellite, was launched in 2007 to track missiles in flight. Its suite of high-performance sensors has collected near-field, high-, and low-resolution images of a boosting rocket. In addition to missile tracking functions, NFIRE operators also execute risk reduction data collections to support future MDA programs for low-earth orbit tracking systems and sea-based Standard Missile programs. In 2011, a German built Laser Communications Terminal payload aboard NFIRE achieved simultaneous atmospheric data collection during a bi-directional (full duplex) laser communications link with the German TerraSAR-X satellite. The satellites communicated approximately 5.6GB data every 7.3 seconds or roughly one DVD worth of data every 3.7 seconds across a separation distance of approximately 10,000 km.


Near Field Infrared Experiment (NFIRE)


Upper Stage Engine Technology (USET)

The Upper Stage Engine Technology effort validated advanced physics-based modeling, simulation, and analysis tools for liquid rocket engines using a high performance turbo-pump. These tools are being used by both industry and government to better understand existing engine designs and develop new engine designs for space launch systems.

The 3rd Generation Infra-Red System Risk Reduction CHIRP sensor, developed for AF SMC and AFRL, offers a wide-field-of-view overhead persistent infrared sensor for early warning of missile launches and to support other military missions. Upgraded from a ground prototype and delivered in less than two years, CHIRP was integrated onto a commercial telecommunications satellite and launched in September 2011.


Commercially Hosted IR Payload (CHIRP) Sensor

The Maritime Automated Supertrack Enhanced Reporting JCTD was successfully transitioned to the National Security Agency (NSA) and the Office of Naval Intelligence (ONI). This JCTD, executed by NRL, US Northern Command and ONI, employed existing space assets to vastly improve global maritime domain awareness. Further technological improvements, including technology to identify activities of critical interest, are being developed.

In 2011, the FCMSSR established the Unified National Space Weather Capability (UNSWC) within the National Space Weather Program (NSWP). The purpose of UNSWC is to coordinate collaborative and cooperative interagency activities to improve space weather science and services. A joint action group for the UNSWC developed an integrated action plan in early 2012

Appendix A: CORE SPACE CAPABILITIES

Satellite Communications (SATCOM) - Provides a seamless, end-to-end, space-based communications (both government owned and leased) system of systems, that is integrated and interoperable both internally and externally.

Missile Warning and Attack Assessment (MW&AA) – Timely and unambiguous detection of ballistic missile launches and nuclear detonations from space.

Positioning, Navigation and Timing (PNT) - Generating and using signals to enable determination of precise location, movement, orientation, and time.

Intelligence, Surveillance and Reconnaissance (ISR) - Space-based systems that collect Geospatial & Signals Intelligence; includes National Technical Means, Commercial/Foreign Family of Systems, and small, rapid-response opportunities, and space situational awareness.

Space Control (SC) - Provide freedom of action in space for US and its allies across the entire space enterprise to ensure: the satellite constellations are more resilient to threats, the military can perform its mission when space is degraded, and the US can deny the adversary's use of space against our forces in conflict.

Space Access (SA) - Delivery, maneuvering, and recovery of payloads to and from space in a responsive, reliable, flexible manner, thereby ensuring assured access to space in peace, crisis, and through the spectrum of conflict.

Space Environmental Monitoring (EM) - Remote sensing and in-situ monitoring of the extended operational environment (near-Earth space), helio-space, and high energy space to accurately specify and forecast conditions using derived data.

Command and Control (C2) - Provides for the exercise of authority over assigned and attached space forces and resources to monitor, assess, plan, and execute space operations at all echelons of command.

Satellite Operations (SATOPS) - Operations conducted to maneuver, configure, operate, and sustain on-orbit National Security Space assets.

Source: National Security Space Plan – 3 May 2010

Appendix B – GOAL AND PROJECT TABLES

Table 1 Satellite Communications

Short Term S&T Goals	Technology Focus	Project Name	Service/Agency	Completion	Key Metric
Communications-on-the-move	RF downlink	TacSat-4 Innovative Naval Prototype (INP)	Navy-NRL	FY 12	Space flight demo (completed)
Reduce size, weight, power, cost, and improve thermal management for SATCOM terminals	Compact laser comm terminal	Compact Laser Terminal (COLT)	AF-AFRL	FY 16	Space flight demo
Support to ISR Collection Platforms	Exfiltration of data	Ocean Data Telemetry MicroSat Link (ODTML)	Navy-NRL	FY 13	Space flight demo
	Downlink laser comm	Automated Navigation and Guidance Experiment for Local Space (ANGELS-SSA)	AF–AFRL	FY 16	Space flight demo
Space-based laser communications for disadvantaged platforms	Diversified, anti-jam, long range comms	Photonic Array Receiver	Navy-NRL	FY 13	Space flight demo
	Laser comm ground station	Compact Laser Terminal (COLT)	AF-AFRL	FY 16	Space flight demo
Dedicated/theater controlled, space enabled tactical communications in contested environments	Comms/data exfiltration nanosatellite	SMDC Nanosatellite Program (SNaP) JCTD	Army-SMDC	FY 14	Up to 56 kpbs, 250 simultaneous text message users and data exfiltration
	Low probability of detection encryption system suitable for laser comm to LEO satellite	Secure Comms	AF-AFRL	FY 17	Space flight demo

Table 1 Satellite Communications, cont'd

Long Term S&T Goals	Subgoal	Project Name	Service/Agency	Completion	Key Metric
Develop/enhance V-, W- and Ka - band radio frequency (RF) communications	GaN solid state amplifiers (ManTech)	V/W Band ManTech	AF-AFRL	FY 14	Transition to acquisition
	Ka band data downlink	Integrated Solar Array and Reflectarray Antenna for High Bandwidth CubeSat (ISARA)	NASA	FY 15	3U cubesat Ka band system – 100 mbps downlink goal
Long Term S&T Goals	**Subgoal**	**Project Name**	**Service/Agency**	**Completion**	**Key Metric**
Space-based laser communications for disadvantaged platforms	Laser comm	Laser Comm Relay Demonstration (LCRD)	NASA	FY 19	Laser comm from GEO
Develop/enhance V-, W- and Ka - band radio RF communications	Increase bandwidth capability and flexibility	Future Space Communications	AF-AFRL	FY 20	Space flight demo
Enhanced protection and resilience in contested environments	Increase bandwidth capability and flexibility	Future Space Communications	AF-AFRL	FY 20	Space flight demo

Table 2 Missile Warning, Missile Defense and Attack Assessment

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Improved sensors for whole Earth sensing	Focal plane development	Protection for Visible and Near Infrared ISR Sensors	AF-AFRL	FY 15	Transition to acquisition
	Improved visible & infrared sensor chip assemblies (SCAs)	Advanced Electro-Optical Space Sensors for ISR	AF-AFRL	FY 17	Transition to acquisition
	Improved cryocooler size, weight and power (SWaP)	Spacecraft Component Thermal Research	AF-AFRL	FY 17	Space flight demo
	Data collection and analysis for future space-based systems	Space Tracking and Surveillance System Demonstrators (STSS-D)	MDA	Ongoing	Space flight demo
Improved data fusion algorithms for space-based MW, MD, & AA capable sensors	Algorithms for midcourse sensors	Command and Control, Battle Management and Communications (C2BMC) Experimentation with Space Tracking and Surveillance System (STSS) for Aegis Launch on Remote	MDA	FY 13	Space flight demo
	Single system track picture from multiple platforms viewing with partially-matching scenes	Advanced Electro-Optical/Infrared (EO/IR) Track Correlation and Fusion Algorithms	MDA	FY 13	Space flight demo
	Robust techniques to correlate tracks from various sensors	Track Correlation	MDA	FY 13	Space flight demo
	Range to target with only one EO/IR sensor for more precise track	Passive Range Estimation from Angle – Angle Data	MDA	FY 13	Space flight demo

Table 2 Missile Warning, Missile Defense and Attack Assessment, cont'd

	Maintain track on maximum number of targets for fire control, cueing and guidance optimization	Sensor Resource Management	MDA	FY 14	Improved performance algorithms
Improved automated analytic techniques for characterization and discrimination	Target signature characterization	Discrimination	MDA	FY 13	Space flight demo
	Advanced missile characterization and typing	Overhead Persistent Infrared Rapid Advanced Characterization from Launch to Engage	MDA	FY 14	Space flight demo
	Data fusion	Sensor Data Fusion	MDA	FY 14	Improved performance algorithms
	EO/IR sensor to discriminate between debris and countermeasure in a dense scene	Multi-Spectral Countermeasure and Debris Identification and Mitigation	MDA	FY 14	Improved performance algorithms
	Detect missile launch under clouds	Signature Exploitation	AF-AFRL	FY 17	Space flight demo
	Data collection and analysis for future space-based systems	Space Tracking and Surveillance System Demonstrators (STSS-D)	MDA	Ongoing	Space flight demo

Table 2 Missile Warning, Missile Defense and Attack Assessment, cont'd

Long Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Reducing the cost of MW, MD, & AA space-based tracking systems	Focal plane development	High Resolution Mid-wave Infrared	AF-AFRL	FY 18	Space flight demo
Improved data fusion algorithms for space-based MW, MD, &AA capable sensors	Develop algorithms for new OPIR data	C2BMC Experimentation and Deployment of Algorithms to Utilize Space Based Infrared System (SBIRS) GEO Scanner/Starer Sensors	MDA	FY 18 (GEO Scanner); FY 20 (GEO Starer)	Space flight demo
	Atmospheric transmission algorithms	Imaging Spectroscopy	AF-AFRL	FY 20	Space flight demo

Table 3 Positioning, Navigation, and Timing

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Improved/enhanced GPS anti-jam capabilities	Digital beamforming phased antenna array	Advanced GPS receiver and adaptive beamforming antennas for multipath rejection	NASA	FY 13	Space flight demo
Improved atomic clocks for space systems	Compact precision molecular clock	Advanced Laser Frequency Stabilization	NASA	FY 13	Space flight demo
	Mercury-ion trap technology	Deep Space Atomic Clock	NASA	FY 14	Improve data quality by 10X; Improve clock stability by 100X
	Low SWaP atomic clock	Cold Atom	AF-AFRL	FY 17	Space flight demo
Continue update of celestial catalog	Ground based telescope observations	USNO Robotic Astrometric Telescope (URAT)	USNO	FY 17	accuracy goal of 5-30 milliarc-seconds
Robust alternative space-based navigation capabilities for GPS-denied environments	Gyroscope based inertial guidance system	Fast Light Optical Gyroscope for Precision Navigation	NASA, Army-AMRDEC	FY 16	Field test/demo
	X-ray receiver for timing and navigation	Station Explorer for X-ray Timing and Navigation Technology (SEXTANT)	NASA, NRL, AFRL, NRO, NIST	FY 17	Space flight demo
	Modernized GPS L2C signal tracking	Space Cube Navigator GPS	NASA	FY 13	Space flight demo

Table 3 Positioning, Navigation, and Timing, cont'd

	GPS antenna characterization	GPS Transmit Sidelobe Antenna Characterization	NASA	FY 13	Space flight demo
	COTS Smart phone as satellite	Phonesat 2 – Innovative Orbit Positioning and Control for Cubesat	NASA	FY 13	Space flight demo
	Advanced inertial guidance technology	Strategic Systems and Launch Technologies	AF-AFRL	FY 17	Transition to operational use
Improved star tracker performance	Star tracker	Development of CMOS star tracker	NASA	FY 14	Space flight demo
	Star tracker	Digital Imaging Star Camera	Navy-NRL	FY 14	Space flight demo
	Star tracker	Miniature Star Tracker	AF-AFRL	FY 12	Space flight demo
Long Term S&T Goals	**Focus**	**Project Name**	**Service/Agency**	**Completion**	**Key Metric**
Robust alternative space-based navigation capabilities for GPS-denied environments	Anti-jam enhancement for GPS assured reception	High Integrity GPS (HiGPS)	Navy-NRL	FY 18-19	Transition to operational use
	Chip based cold atom gyroscope	Cold Atom	AF - AFRL	FY 19	<10m/hr drift
	Nav & timekeeping GPS alternative in space	Astrophysical Clocks and X-ray Navigation	Navy–NRL	FY 25	Simulation of space-based x-ray pulsar navigation and timing capability

Table 3 Positioning, Navigation, and Timing, cont'd

	Low-cost GPS adjunct	Advanced GPS technologies	AF-AFRL	FY 20	Space flight demo
Complete update of celestial catalog	Atmospheric interferometer	Navy Precision Optical Interferometer (NPOI)	USNO	FY 19	accuracy of ~ 10 milliarc-seconds

Table 4 Intelligence, Surveillance, and Reconnaissance

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Increased persistence of space- based ISR	Thermal Infrared Sensor	LandSat	NASA	FY 13	Launch
	COTS Smart phone as satellite	Phonesat 1 – Earth Imagery	NASA	FY 13	Space flight demo
	Small, disposable, low cost constellations for persistent ISR	SeeMe	DARPA, Army-SMDC, AMCOM	FY 14	Space flight demo
	Wirelessly-interconnected space craft modules for secure resource sharing	System F6	DARPA, NASA, Navy-NRL	Ongoing	Space flight demo
	Fusion algorithms for "A-train" satellite data	Global Modeling and Assimilation Program	NASA	Ongoing	Space flight demo
Improved use of space assets through cross-cueing, integrated commanding, fusion of data products and tailored data distribution	Improved detection, cross-cueing, fusion and tailored distribution of data products	Detection and Fusion of Remote Sensors	Navy-NRL	FY 17	Space flight demo
Fully integrated space-, air-, and ground-based ISR systems to enhance worldwide persistent coverage	Tactical imaging spacecraft	Kestrel Eye JCTD	Army-SMDC	FY 14	Launch call up to satellite imagery in < 48 hrs

Table 4 Intelligence, Surveillance, and Reconnaissance, cont'd

Long Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Fully integrated space-, air-, and ground-based ISR systems to enhance worldwide persistent coverage	Detect high interest materials, facilities, and activities in denied areas from space	Imaging Spectroscopy	AF-AFRL	FY 20	Actionable intelligence
Comprehensive knowledge of man-made orbital objects irrespective of size or location	Spacecraft interferometric imaging techniques	Imaging with the Naval Precision Optical Interferometer (NPOI)	Navy-NRL	FY 20	Space flight demo

Table 5 Space Control and Space Situational Awareness

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Improved space object detection, conjunction and drag prediction, mitigation and potential remediation	Conjunction prediction & orbit trajectory propagation tools	High Performance Computing Software Applications Institute for Space Situational Awareness (HSAI-SSA)	AF-AFRL	FY 15	Demo
	Ground-based laser for identification and tracking of orbital debris	Ground-based Laser Ranging at NASA-GSFC	NASA	FY 15	Space flight demo
	Ground-based optical detection and tracking of deep space objects	Space Surveillance Telescope (SST)	DARPA	FY 16	Ground demo
Improved monitoring of potential space-based threats	Collaborative space information fusion	Space Domain Awareness (SDA)	DARPA	FY 16	Ground demo
	Image resident space objects (RSOs)	Autonomous Nanosatellite Guardian for Evaluating Local Space (ANGELS)-SSA	AF-AFRL	FY 16	Space flight demo
	Timely LEO imaging of dim LEOs and LEO-GEO CSO detection	Characterization Enhancement Using Adaptive Objects	AF-AFRL	FY 16	Dim object imaging
	Daylight characterization of objects	Advanced Characterization Techniques (ACT)	AF-AFRL	FY 16	Daylight imaging
	Affordable deep space imaging	SSA Integration Group	AF-AFRL	FY 17	Transition to flight experiment
	Detect, track and assess threats	Spacecraft Awareness Sensors	AF-AFRL	FY 17	Integrated sensor suite

Table 5 Space Control and Space Situational Awareness, cont'd

Technologies to increase protection and resiliency of space capabilities	Spacecraft ID/characterization	SSA Integration Group – Multi-sensor Exploitation for Space Situational Awareness (MESSA)	AF-AFRL	FY 13	Correlation of pre- and post-launch measurements
	Detect, track and assess threats	Spacecraft Awareness Sensors	AF-AFRL	FY 17	Integrated sensor suite
	Space object ID/characterization	Space Fusion, Assessment & Characterization for Threat Prediction (Space FACT)	AF-AFRL, DARPA	Ongoing	Increase warning time/reduce analysis time
Technologies to increase cross-domain capabilities to enhance resilience	Optical downlink	Integrated Optical Communications and Proximity Sensors Demonstration (OCSD)	NASA	FY 15	Demonstrate optical comm from LEO
	Integrate all-source info with new observations to identify & characterize space objects	EO Integration & Innovation Center	AF-AFRL	Ongoing	Transition to operational use
Enhanced SSA, including data processing	Data registration software	Toolbox for Automated Registration and Analysis (TARA)	NASA	FY 13	Transition to operational use
	Collaborative space information fusion center	Space Domain Awareness (SDA)	DARPA	FY 14	Space flight demo
	Ground-based optical detection and tracking of deep space objects	Space Surveillance Telescope (SST)	DARPA, USNO	FY 16	Ground demo

Table 5 Space Control and Space Situational Awareness, cont'd

Long Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
	Automated threat detection/response	Decision Support Systems – Space Situation Awareness Fusion Intelligent Research Environment/Joint Space Operations Center Mission System (SAFIRE/JMS)	AF-AFRL	FY 16	Space flight demo
	Reduce space object tracking error	Guidance, Navigation and Control	AF-AFRL	FY 17	80% reduction track error
Improved capabilities to detect and characterize space objects	Resolve GEO-belt space objects	Space Object Surveillance	AF-AFRL	FY 15	Resolve objects in < 10 min
	Laser-based tracking of orbital debris	Ground-based Laser Ranging for ID and Tracking of Orbital Debris	NASA	FY 15	Space flight demo
	Image deep space objects	SSA Integration Group	AF-AFRL	FY 17	Space flight demo
Long Term S&T Goals	**Focus**	**Project Name**	**Service/Agency**	**Completion**	**Key Metric**
Achieving the capability to deter, inhibit, delay, or dissuade an adversary from impeding U.S. or Allied nation access to or use of the space domain	Proof-of-concept for HAND remediation	Radiation Belt Remediation, Demonstration and Science Experiment (DSX) - Flight	AF-AFRL	FY 18	Space flight demo
	Proof-of-concept for HAND remediation	Innovative NanoSat Flight Experiment Series	AF-AFRL	FY 18	Space flight demo
	Space collision risk reduction	Elimination of Space Debris via Drag	Navy–NRL	FY 18	Demo of suborbital dust-based active debris removal

Table 5 Space Control and Space Situational Awareness, cont'd

	Near-space radiation effects characterization	High Energy Radiation Detection	Navy–NRL	FY 18	Demo of WMD rad/nuke detection w/ advanced imaging x-ray and gamma-ray detectors
	Collision avoidance predictive tools	Cloud Dynamics of Satellites	Navy–NRL	FY 19	Demo of orbit determination & satnav with probabilistic modeling and drag software
	Near-space radiation effects characterization	Terrestrial Gamma-ray Flashes (TGFs)	Navy–NRL	FY 20	Demo of TGF radiation signatures estimator
	Near-space radiation effects characterization	Terahertz (THz) Observations	Navy–NRL	FY 23	Demo next-gen THz optical components for detection of special nuclear material
Achieving the capability to maintain mission assurance in a degraded space environment	Assess threats, model, design and test satellite protection concepts	Satellite Vulnerability & Protection	AF-AFRL	FY 18	Transition to operational use

Table 5 Space Control and Space Situational Awareness, cont'd

	Radiation displacement damage effects	Realtime Radiation Displacement Damage	Navy–NRL	FY 18	Tech demo with prototype low SWaP-C device
Improved monitoring of potential space-based threats	Imaging of GEO objects	Long Range Imaging LADAR	AF-AFRL	FY 18	Tech demo
	Daylight monitoring of GEO objects, dynamic tasking of sensors, astrodynamics	Satellite Object Custody	AF-AFRL	FY 19	Networking of telescopes
	Improve sky surveillance coverage using next-gen optics & photonics	Advanced Technologies for Extreme Conditions (ATEC)	AF-AFRL	FY 18	Testing of next-gen adaptive objects
	Deep space imagery, change detection research & anomaly identification	High Power Electro-Magnetics (HPEM) for Space Superiority	AF-AFRL	FY 19	Space flight demo
Comprehensive SSA, including data processing	Space-generated ground force nanosat tasking and control	Space Tactical Processing, Exploitation & Dissemination (TPED) Demos	Army –SMDC	FY 19	Distributed Common Ground System – Army (DCGS-A) Interface Demos
Comprehensive knowledge of man-made orbital objects irrespective of size or location	Spacecraft interferometric imaging techniques	Imaging with the Naval Precision Optical Interferometer (NPOI)	Navy-NRL	FY 20	Space flight demo

Table 6 Space Access

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric

Reduce launch cost and cycle time	Enable low-cost secondary payloads	Flight Experiment – EAGLE	AF-AFRL	FY 16	Space flight demo
	Cryogenic loading system monitor	Autonomous Systems Project	NASA	FY 15	Test
	Spinning slosh testing on SPHERES satellites	ISS Synchronized Position Hold Engage and Reorient Experimental Satellites (SPHERES) Fluid Slosh	NASA	FY 14	Test
	Insulation technology development	Self-supporting High Performance Multi-Layer Insulation Technology Development (SSMLI)	NASA	FY 13	Tank test
	Acoustic suppression	Lightweight High Performance Acoustic Suppression (HiPAcS) Technology Development	NASA	FY 15	Test
	Orbital transport for nanosatellites	Nanolauncher Technologies Initiative	NASA	FY 15	Launch of <50kg payload
	Low cost, persistent and responsive space access	Small Responsive Space Access X-Plane	DARPA	FY 14	Space flight demo
	Space Technology	Overcoming Low Nozzle Efficiency	Navy-NRL	FY 15	Space experiment demo
More flexible launch operations and improved range safety technologies	Launch vehicle	Soldier-Warfighter Operationally Responsive Deployer for Space (SWORDS)	NASA, Army-SMDC	FY14	Space flight demo

Table 6 Space Access, cont'd

	Advanced solar electric propulsion	Solar Electric Propulsion Space Experiment (SEP-SX)	DARPA	FY 14	Space flight demo
	Small satellites launched from an airborne platform at LEO	Airborne Launch Assist Space Access (ALASA)	DARPA, NASA	FY 14	Space flight demo
Technologies to expand opportunities to employ commercial space assets synergistically	On-orbit technologies	Propulsion Unit for CubeSat	AF-AFRL	FY 16	Space flight demo
	Broker shared rides for scientific and tech-demo payloads	NASA GSFC Payload Rideshare Program	NASA	Ongoing	Rideshares
Expand launch options for space experiments	Expendable launch system	Super Strypi - Spaceborne Payload Assist Rocket-Kauai (SPARK)	OSD, AF-ORS	FY 13	Launch
Higher performance on-orbit propulsion	Liquid propulsion	Advanced Liquid Propellant	AF-AFRL	FY 16	70% performance improvement
	"Green" fuel	Green Propellant Infusion Mission (GPIM)	NASA	FY 16	Space flight demo
Long Term S&T Goals	**Focus**	**Project Name**	**Service/Agency**	**Completion**	**Key Metric**
Enable reduced, cost-flexible, on-demand launch	Liquid propulsion	Hydrocarbon Boost	AF-AFRL	FY 20	Brassboard demo
Technologies to expand opportunities to employ commercial space assets synergistically	On-orbit propulsion	High Power Electric Propulsion	AF-AFRL	FY 18	Space flight demo

Table 7 Space and Terrestrial Environmental Monitoring

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Improved understanding and awareness of the Earth-to-Sun environment	Coronal mass ejection impacts	Advanced Radiation Protection (includes ISEP Project and MC-CAD Analysis)	NASA	FY 14	Fielding of analysis tools
	Three dimensional local radiation modeling	Miniature Array of Radiation Sensors (MARS)	NRL	FY 14	Space flight demo
	Measure MEO space environment	Flight Experiment – DSX	AF-AFRL	FY 16	Flight experiment
	Solar wind measurements	Deep Space Climate Observatory (DSCOVR)	NASA	FY 15	Space flight demo
	Hazardous spacecraft charging early warning	Spacecraft Plasma Diagnostic Suite	Navy-NRL	FY 15	Demo prototype spacecraft charging probe
Improved space environment forecast capabilities and tools to predict operational impacts	Improve orbit determination and prediction	Small Wind and Temperature Spectrometer (SWATS)	NRL	FY 14	Space flight demo
	Forecast agent for NASA's robotic missions	Space Weather Research Center	NASA	Ongoing	Space flight demo
Improved space environmental sensors	Extended operational environment characterization	Ground-based Round-the-Clock Auroral Observations	Navy-NRL	FY 15	Transition for operational use
	Web-based analysis tools	Integrated Space Weather Analysis (iSWA)	NASA	Ongoing	Transition to operational use

Table 7 Space and Terrestrial Environmental Monitoring, cont'd

Long Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Improved space environment forecasting and enabling real-time threat warning	Spacecraft attitude and environment sensing	Ram Angle & Magnetic Field Observations	Navy-NRL	FY 18	Demo prototype low SWaP-C sensor suite for a PicoSat
	Extended operational environment (EOE): heliospace characterization	Spectroscopic Techniques for Space Wx	Navy–NRL	FY 19	Demo next-gen EUV spectroscopic space-borne instrument
	EOE: heliospace characterization	Non-linear Excitation of Space Plasmas	Navy-NRL	FY 19	Space flight demo of artificial ionospheric layer generation
	EOE: heliospace characterization	Thermospheric Wind Instrumentation	Navy-NRL	FY 19	Demo next-gen thermosperic winds space-borne instrument
	EOE: geospace characterization	Linking Lower Atmosphere to Ionosphere	Navy–NRL	FY 20	Transition to operational use

Table 7 Space and Terrestrial Environmental Monitoring, cont'd

	Solar energetic particle (SEP) characterization	Seed Populations for Large SEP Events	Navy–NRL	FY 21	Demo numerical model of high-energy SEP and solar gamma ray emissions
	Advanced space weather instruments	Space Particle Hazards Specification and Forecast	AF-AFRL	FY 22	Transition tools and components for operations
	Space forecast tools	Ionospheric Impacts - Space Weather Forecasting Laboratory (SWFL)	AF-AFRL	FY 22	Transition to operational use
	Ionosphere models and mission impact	Ionospheric Impacts - SSA/ISR	AF–AFRL	FY 22	Transition to operational use
	Neutral density and wind forecast	Ionospheric Impacts - Orbital Drag	AF-AFRL	FY 22	Transition to operational use
	Coronal mass ejection models	Solar Disturbance Prediction	AF-AFRL	FY 22	Transition to operational use
Marine meteorology and prediction using space assets	Development of soil moisture retrieval algorithm	WindSat	Navy–NRL	FY 18	Transition to operational use
	Aerosol observation, prediction and understanding	Exploitation of Satellite Data for Characterization of the Environment	Navy–NRL	FY18	Transition to operational use
	Generate global atmospheric analysis fields	Atmospheric Navy Global Environmental Model (NAVGEM)	Navy–NRL	FY18	Transition to operational use

Table 7 Space and Terrestrial Environmental Monitoring, cont'd

	Improve prediction of tropical cyclones	Coupled Ocean-Atmospheric Mesoscale Prediction System – Tropical Cyclone (COAMP-TC)	Navy–NRL	FY18	Transition to operational use
	Ocean and coastal measurement	GEOstationary Coastal and Air Pollution Events (GEO-CAPE) – (Part of NASA Decadal Survey Program)	NASA	FY 20	Technology demo
Improved understanding and awareness of the Earth-to-Sun environment	Extend magnetohydrodynamic models of solar activity to improve comm and mag impact prediction	Tracing the Origins of the Solar Wind	Navy-NRL	FY 18	Transition to operational use
	Hazardous S/C charging early warning	Spacecraft Plasma Diagnostic Suite	Navy-NRL	FY 18	Space flight demo
	Extended operational environment (EOE): heliospace characterization	Integrating the Sun-Earth System	Navy–NRL	FY 19	Transition to operational use

Table 8 Command and Control and Satellite Operations

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Increased autonomy for C2 systems to reduce manning	Order of magnitude improvement in space planning capabilities	Space Planning Services	AF-AFRL	FY 13	Event resolution in <60 min
Technologies enabling highly efficient on-orbit maneuvers and longer on-orbit life	Improved rendezvous and proximity operations (RPO) performance	Guidance, Navigation and Control	AF-AFRL	FY 17	GEO GPS position determination
Space robotic capabilities with internal decision-making for on-orbit inspection, servicing, repair, assembly, harvesting sub-systems and life-extension	Robotic technology development	Human Robotics Systems	NASA	FY 14	Demo on extreme terrain testbed
	Harvest and re-use of retired, non-working satellites/components in GEO	Phoenix	DARPA, NASA Navy -NRL	FY 16	Space flight experiment
	Robotic satellite servicing	Robotic Refueling Mission (RRM)	NASA	Ongoing	Space flight demo
Long Term S&T Goals	**Focus**	**Project Name**	**Service/Agency**	**Completion**	**Key Metric**
Space robotic capabilities with internal decision-making for on-orbit inspection, servicing, repair, assembly, harvesting sub-systems and life-extension	Tactical space robotics	Robotic Tactile Sensing for Detection	Navy-NRL	FY 22	Demo of tactile robotic skin for constrained-environment

Table 8 Command and Control and Satellite Operations, cont'd

Fully autonomous systems	Spacecraft propulsion	Space Plasma EM Lab Investigation	Navy-NRL	FY 19	Laboratory chamber demo
	On-board autonomous system to operate through anomalies and threats	Decision Support Systems – Autonomous Ops	AF-AFRL	FY 20	Technology demo
	Spacecraft propulsion	Enabling Technologies for EM Vehicle	Navy-NRL	FY 21	Space flight demo

Table 9 Space Enablers

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Standardized and miniaturized components and interfaces for satellite buses and payloads	Rad-hard	System-on-a-Chip (SOC) Advanced Packaging	NASA	FY 13	Prototype chips
	Easier spacecraft integration	Space Plug-and-Play Avionics	AF-AFRL	FY 14	Completion of open source hardware and software
Technologies to reduce costs and improve performance of satellite buses, payloads, and components	Advanced space structures	Integrated Structural Systems	AF-AFRL	FY 17	Transition to acquisition
	Next generation space electronics	Space Electronics Technology	AF-AFRL	FY 17	Transition to acquisition
	Robust M&S tools for tech assessment/investment decisions	Modeling, Simulation, Evaluation and Assessment	AF-AFRL	FY 17	Transition to operational use
Improved key building blocks for future responsive space systems	Wirelessly-interconnected space craft modules for secure resource sharing	System F6	DARPA, NASA, Navy-NRL	Ongoing	Space flight demo
	Flexible/adaptable satellite crosslink	Edison Demonstration of Small Networks (EDSN)	NASA	FY 14	Maintaining crosslinking for 8 cubeSats
	Ground system development	Goddard Mission Services Evolution Toolbox	NASA	Ongoing	Publication of standards

Table 9 Space Enablers, cont'd

Disruptive technologies enabling transformational space capabilities (e.g. Carbon based nanotechnology)	Contamination mitigation	Lens Cleaning via Electrons	NASA	FY 13	Ground test
	Mitigation of total ionizing dose (TID) exposure	Efficient Radiation Shielding Through Direct Metal Laser Sintering (DMLS)	NASA	FY 13	Prototype chips with advanced shields
	Microsatellite testbeds for multi-body formation flight experiments	International Space Station SPHERES Integrated Research Experiments (InSPIRE)	DARPA, NASA, Navy-NRL	FY 14	Space flight demo
Long Term S&T Goals	**Focus**	**Project Name**	**Service/Agency**	**Completion**	**Key Metric**
Ultra-high-efficiency power system components, such as solar cells, batteries, and adaptive point-of-load converters	Space qualified solar cells	Advanced Inverted Metamorphic (IMM) Multi-junction Solar Cells	AF-AFRL	FY 18	33% efficient cells transitionable to acquisition
	Spacecraft energy efficiency	Steerable Spacecraft Radiator	Navy-NRL	FY 18	Space flight demo
	Space energy novel systems	Photovoltaic RF Converter Antenna	Navy-NRL	FY 22	Space flight demo
Maximize satellite dry mass reduction through game-changing technologies	High-density memory and processing	Space Electronics Technology	AF-AFRL	FY 22	Space qualification of chips

Table 9 Space Enablers, cont'd

Technologies that facilitate integrating U.S. architectures with international and commercial partner systems and technologies	Real-time data fusion and dissemination	Inter-operable Architecture for Sensor Webs	NASA	Ongoing	Increase in number of participating sites