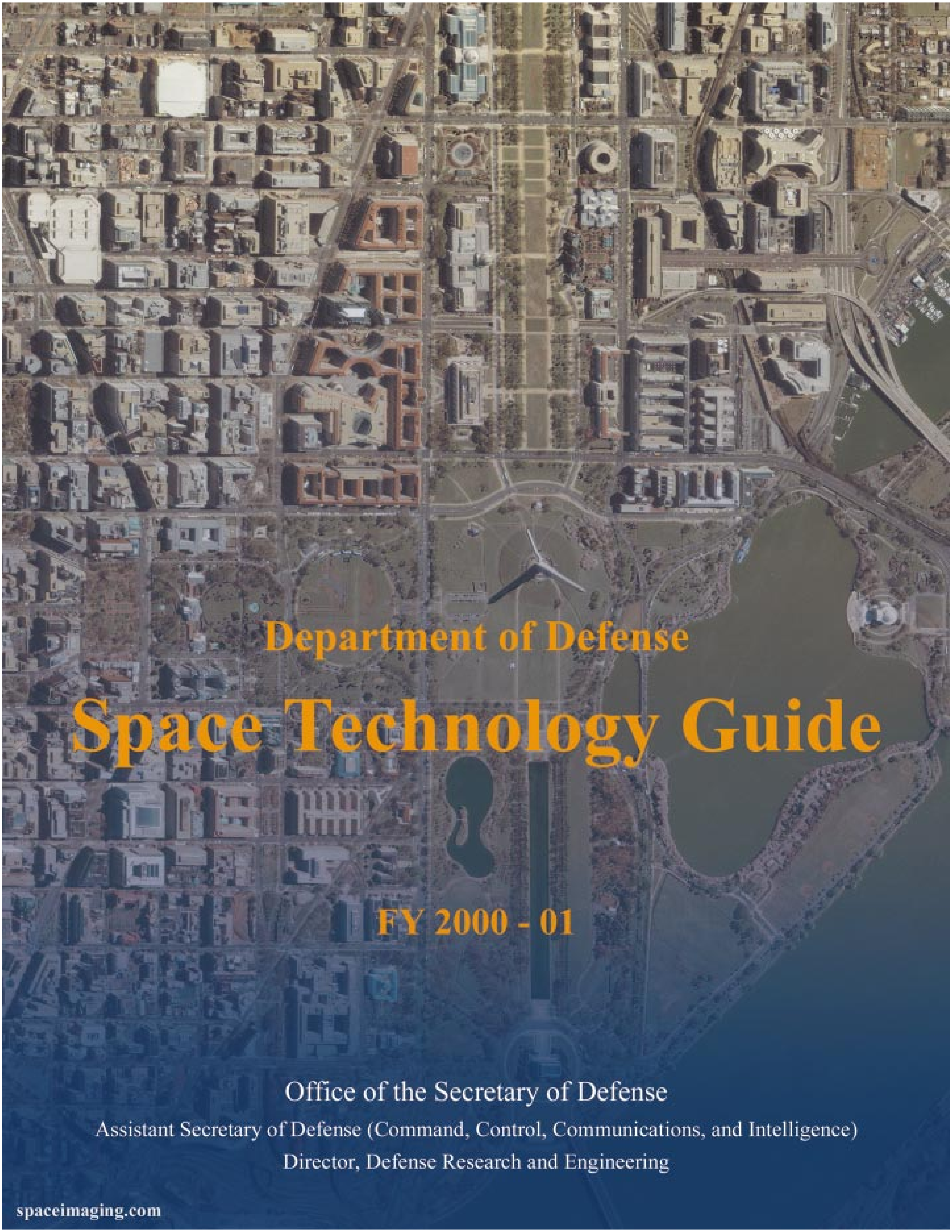

Department of Defense

Space Technology Guide

FY 2000 - 01

Office of the Secretary of Defense

Assistant Secretary of Defense (Command, Control, Communications, and Intelligence)

Director, Defense Research and Engineering

spaceimaging.com

Foreword

Space-based capabilities are integral to the U.S.'s national security operational doctrines and processes. Such capabilities as reliable, real-time high-bandwidth communications can provide an invaluable combat advantage in terms of clarity of command intentions and flexibility in the face of operational changes. Satellite-generated knowledge of enemy dispositions and movements can be and has been exploited by U.S. and allied commanders to achieve decisive victories. Precision navigation and weather data from space permit optimal force disposition, maneuver, decision-making, and responsiveness. At the same time, space systems focused on strategic nuclear assets have enabled the National Command Authorities to act with confidence during times of crisis, secure in their understanding of the strategic force postures.

If our Armed Forces are to be faster, more lethal, and more precise in 2020 than they are today, we must continue to invest in and develop new military capabilities.
Joint Vision 2020

Access to space and the advantages deriving from operating in space are being affected by technological progress throughout the world. As in other areas of technology, the advantages our military derives from its uses of space are dynamic. Current space capabilities derive from prior decades of technology development and application. Future capabilities will depend on space technology programs of today. Thus, continuing investment in space technologies is needed to maintain the "full spectrum dominance" called for by Joint Vision 2010 *and* 2020, *and to protect freedom of access to space by all law-abiding nations.*

Trends in the availability and directions of technology clearly suggest that the U.S. pursue its national security space interests vigorously. Dynamics to be addressed by DoD technology investments include:

- *Predictability of our space assets vs. denial and deception techniques employed by opposing forces*
- *The ready availability and military utility of commercial technology for other clients as well as ourselves*
- *Proliferation of ballistic missiles with the risk of nuclear, biological or chemical warheads*
- *The effects of budgetary constraints, which in turn require new concepts and technologies to overcome them*
- *Increasing risks of electronic and cyber attack*
- *The possible need for offensive as well as defensive space operations.*

To counteract these trends, many enhancements and applications of current space technologies are being pursued. The strategy for investing in space technology includes the following approaches:

- Cost reduction – *to be achieved to a significant degree by continuing miniaturization and new paradigms*
- New sensors – *to detect smaller, moving or concealed targets under all environmental conditions*
- On-orbit data processing and artificial intelligence – *to reduce human operator costs and burdens on the communications infrastructure*
- Launcher and propulsion developments – *to reduce costs to orbit and facilitate on-orbit maneuverability*
- On-orbit servicing capabilities – *to extend space system life and upgrade its capabilities*
- Surveillance, defensive and offensive technologies – *to support space control, information operations, and force application.*

These and other operational and technology concepts are summarized in this DoD Space Technology Guide.

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8. Intelligence, Surveillance, and Reconnaissance

Area Description

Joint Vision 2020 depends on information superiority for virtually every aspect of military activity. The combination of intelligence, surveillance and reconnaissance (ISR), together with real-time communications and information processing technologies, is its enabler. It involves primarily electronic systems to find, watch and collect data from sources and provide it as information to users.

ISR permeates almost every area of national security activity, from peace through war. It involves techniques and systems operating both passively and actively in all operational environments from subsurface to space. A key benefit of this capability, from data collection through warning to its timely use by warfighters, is political and/or military success — through knowing more and knowing it sooner than opponents.

ISR includes information about: all operational threats to U.S. and Allied lives, assets, and interests; military force movements; all spacelift vehicles, missile systems (mobile or fixed), and spacecraft; all aircraft types, land-operating systems, and surface/submerged maritime vessels; nuclear detonations; threats to friendly space assets; chemical and/or biological weapons; and other significant space, surface and subsurface events. ISR activities support the intelligence and warning needs of all Services, the National Command Authorities (NCA) and other government agencies, support U.S. and Allied operations, and assist in international treaty monitoring.

The major goal of ISR is success through information dominance. Increasing demands for precise, finished intelligence on a wide range of defense intelligence requirements strain the resources currently available. Space-based intelligence collection capabilities have matured into powerful and reliable systems, able to meet a much larger fraction of the validated user requirements than ever before. Under today's exploitation and dissemination paradigms, our available personnel, communications and hardware cannot fully utilize the available data. Thus the Intelligence Community is pursuing a full range of technologies not only to enhance the collection of necessary data but also to examine new ways to produce and disseminate the information our users need. This approach includes:

- New and potentially revolutionary collection systems
- New analysis and dissemination methods and paradigms
- Significant improvements in data processing, storage-retrieval, and request-redistribution functions.

An evolving concept to deal with the multiplicity of evolving ISR and related information distribution concepts is contained in the term "infosphere." This construct involves information collection and integration across all activities (fusion), with follow-on processing to tailor its disseminated products for specific warfighters and other users.

Specific concerns and evolving needs include the following:

- The orbits of space-based ISR systems are currently predictable. However, if (per SatOps concepts) it becomes possible to maneuver them at will, an adversary would find it much more difficult to avoid detection or to interfere with them. Further, if they could be refueled on-orbit, they could be maneuvered to counter adversaries' operational planning or direct attack, without shortening mission life.
- Infrared detection of missile launches remains a key element of tactical warning; hence DoD's support for the Space-Based Infrared System (SBIRS) program as a replacement for the aging Defense Support Program (DSP) warning satellites.
- A space-based radar capability is needed to enable continuous (24-hour) full-global coverage. Benefits would include precision maps, detection and continuous tracking of sea, ground and air moving targets, and accurate real-time determination of orders of battle (OOBs).

- Proliferation of nuclear/biological/chemical (NBC) weapons requires counterproliferation technologies and capabilities as soon as practical.
- Transition from legacy systems to new ones, such as elevation of Airborne Warning and Control System (AWACS) and Joint Surveillance and Target Attack Radar System (JSTARS) capabilities to space and the increasing use of unmanned aerial vehicles (UAVs) and space sensor platforms, is needed to meet the ISR needs of warfighters everywhere.

Mission Area Objectives

- Global day/night all-weather surveillance and reconnaissance (as basis for situational awareness)
- Timely threat warning infomation (land, sea, air, and space)
  - Detect, track and ID ballistic and cruise missiles, and fixed or moving objects, signals or signatures, worldwide
  - Locate missile launch points, predict their impact points
- Real-time detection, ID, characterization and geolocation of fixed surface/subsurface and mobile targets:
  - Target set detection/surveillance/monitoring/tracking
  - Information on camouflaged, concealed and deceptive (CC&D), deeply buried and other "hard" targets
  - Ability to defeat attempts to schedule activities to avoid detection
- Information on NBC weapons and events
- Intelligence planning, tasking, cross-cueing, fusion, processing, and dissemination

Supporting Capabilities

Modular spacecraft designs for efficient integration, launch and on-orbit “plug and play”

Tactical agility with minimal involvement of ground support personnel

On-orbit propulsion to maneuver spacecraft at will

Higher data rate communications and information processing for fixed and mobile users

Flexible, multi-level information security

On-board processing

Automated cross-cueing

Efficient space-to-space crosslinks

Adaptive, autonomous sensors

Continuous surveillance/long-dwell coverage

Systemic counter-countermeasures

Elevation of AWACS and JSTARS capabilities to space

Surveillance platforms with ultra-lightweight deployable optics and antennas

Combined GMTI and SAR imaging from space

Constellations to provide global coverage

Space-based NBC materials detection

Advanced multi-, hyper- and ultra-spectral information content collection and exploitation

Enhanced target-to-background contrast ratios, target signature characterization, and modeling

Improved characterization of hardened and deeply buried targets

Current Technology Initiatives *(Highlights of Current FYDP)*

Near-term focus is on multi-mission technologies that have application to both air and space surveillance missions. Two such areas are hyperspectral imaging (HSI) and space-based radar (SBR) development.

The HSI program is developing day/night HSI technology capable of rapid precision threat identification and targeting of space, air and surface targets with a longer-term space goal of HSI systems on orbit as part of a national HSI architecture. Technologies include high-resolution focal planes, long-life cryocoolers, on-board signal processing, spectral exploitation algorithms, atmospheric compensation (both reflective and emissive), generation of spectral databases of targets and backgrounds, data fusion technologies, and high-performance computing and displays.

Per Congressional guidance on SBR development, both specific and generic technologies are being pursued:

- Specific projects applicable to airborne and ground moving target indication (AMTI/GMTI) SBR concepts include: affordable, lightweight active transmit/receive antenna modules, spacecraft power management and distribution, and high-efficiency microwave transmit and receive devices
- Generic technology areas extensible to SBR functions include ISR modeling and simulation, bistatic clutter characterization, space-time adaptive algorithm development, improved front-end noise rejection for RF systems, analog-to-digital converters, and advanced RF systems.

The NRO is continuing to develop low-cost Electronically Scanned Array (ESA) technology initiated under the former joint Discoverer II program. In addition, the NRO is examining opportunities and concepts of operations for radar-related experiments and demonstrations using currently available assets.

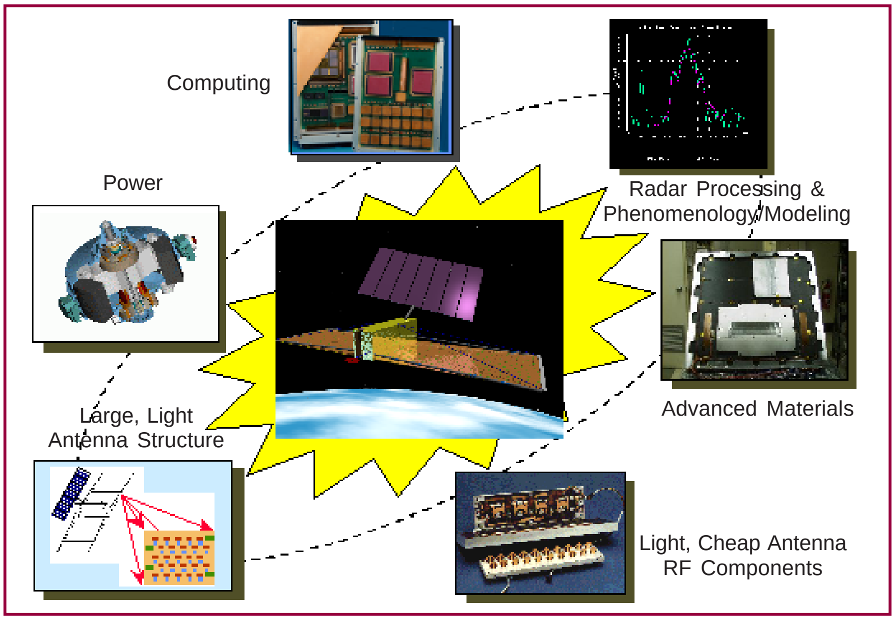
Additional projects and detail are tabulated in “Projected Applications,” below.

Enabling Technologies *(Unconstrained)*

- Autonomous, adaptive, self-training, error-correction and real-time planning algorithms for tasking, mission planning/management, target ID/tracking and battlefield learning, and data compression, processing, exploitation, and dissemination
- Automated cross-cueing, dynamic database fusion, geographic information systems (GIS), and synergy of imaging, spectral and signal functions, phenomena and information technologies
- Increased satellite on-board data processing and storage for timely data delivery
  - Non-volatile random access memory
- ISR modeling and simulation
- Miniaturized, scalable, power-efficient electronic components and mechanisms
  - E.g., fiber optics, optoelectronics, photonics, microelectromechanical systems (MEMS)
  - E.g., high-temperature superconducting electronics to eliminate need for sensor cryocooling
- Large, lightweight support structures and materials
- Shape memory techniques and alloy materials
- Active and passive electromagnetic spectrum devices to direct, disseminate, focus and transmit — as well as to detect, extract, sense and receive — energy:
  - Heat (infrared [IR])
  - Visible light
  - Radio frequency (RF)
- Fusion processing software algorithms
- Increased sensor range and sensitivity technologies
  - Atmospheric and radiant background characterization, modeling, and processing

- Improved atmospheric compensation and target classification algorithms for multi-spectral/hyperspectral image processing
- Exploitation technologies for bistatic phenomenology of targets and clutter characteristics
  - Bistatic space-time adaptive processing algorithm validation
  - True time-delay processing
- Multistatic time and frequency correlation, signal processing, and data fusion
- Advanced target detection technologies
  - E.g., acousto-optical detection and spectral signature exploitation (to see through clouds)
- Non-intrusive inspection technology
- Advanced electro-optical (EO) technology
- Hyperspectral sensing: improved low-power high-capacity on-board processors
- Hyper- to ultra-spectral imagery (HSI-USI) sensors (100s to 1000s of bands)
- Advanced IR technologies
  - Quantum cascade and interband semiconductor IR laser sources
- Multispectral/hyperspectral and very short wavelength infrared (VSWIR) sensors/imagers
  - Multi- to ultra-spectral detector materials, processes, and manufacturing
- Large focal plane array (FPA) detector materials science and manufacturing
  - E.g., staring FPAs for multispectral detection, read-out integrated circuits (ROICs), quantum well IR photodetectors (QWIPs)
- Advanced small, high-capacity, space-qualified cryocoolers
  - More efficient on-orbit storage of cryogenic hydrogen
  - More efficient infrared applications
  - Advanced regenerator/phase-change materials
- Low-power laser atmospheric compensation and beam control
  - Optical phase conjugation
  - Adaptive laser optics
  - On-orbit dimensional control
  - Jitter and vibration management
- Advanced acquisition, pointing and tracking techniques
- Space-based high-resolution optical/radar/multi-spectral imaging technologies (active or passive)
- Space-based laser, lidar or relay mirrors for remote optical sensing
  - Large-aperture, lightweight, modular, deployable membrane mirrors/optics, and support structure materials
- Durable thin-film substrate/membrane/coating materials, processing, and manufacturing
- Nonlinear optical materials for specialized sensors and biological/chemical threat detection
- Optically efficient and variable-emittance mirror coatings
- On-orbit servicing of mirror coatings
- Advanced RF technology
  - Photonics for phase-shifting and beam-forming
  - Spectral analyzers and algorithms
  - Digital RF memory (DRFM)
- Advanced synthetic aperture radar (SAR)
  - E.g., inverse and interferometric SAR
- Advanced automatic target recognition (ATR), moving target indication (MTI), and orbital dynamics processing algorithms
- Large affordable, lightweight RF reflectors and antenna designs
  - E.g. inflatables, deployable array-fed reflectors
  - E.g. solid state phased array electronically steerable antennas
  - Higher strength-to-weight and composite materials and designs
- Radar components with higher frequency and power output
  - High-temperature semiconductor materials for RF/radar components

  - W-band low noise vacuum electronics
  - X-band solid state (wide bandgap) components
- Technologies for receivers, waveforms and antennas to enable:
  - Penetration of clouds, obscurants, foliage, and terrestrial structures
  - Control/adjustment of signals, power, and frequencies to enable better signal penetration and jam-resistance
- Advanced, lower-cost, higher-frequency/bandwidth transmit/receive (T/R) components
- Improved front-end noise rejection for RF systems
- Advanced mixers and analog-to-digital (A/D) converters
- Advanced signal excision techniques
- Laser/optical communications and associated acquisition/tracking/pointing for space-space, space-air, and space-ground applications
- Non-volatile memory optical computing/communications
- Advanced laser and microwave communications technologies for space-space, space-air, space-ground links
  - Advanced netting and encryption technologies
- Reprogrammable radios and other electronics system components
  - Field programmable gate array (FPGA) technologies
- More efficient solar cells, batteries (chemically or thermally generated electricity, such as thermionic power generation and thermo-electric conversion)
  - E.g., lithium ion/polymer hybrid batteries
  - Affordable solar cell materials and manufacturing
- Radiation hardening and shielding of components
  - Radiation-resistant composites and associated materials
  - High-temperature and radiation-resistant electronic materials
  - Flash radiation-hardened digital memory (e.g., SiC)
- Satellite laser and RF interference/vulnerability mitigation
  - Bi-/multistatic techniques
  - Synthetic/virtual apertures
- Isothermality technologies
- High heat-dissipating thermal doubler/plane materials
- Advanced effects phenomenology
- Human-system interfaces for information exploitation and decision-making
- Control center technologies
  - Write once read many (WORM) storage
  - Archival mass storage.



Space-Based Radar (SBR) Concept

Projected Applications

These unclassified technology and program listings represent a major portion of ISR technology investment. Other initiatives, programs and collaborations are classified.

Category	Project / Activity	Status	Agencies
Advanced Target Detection and Imaging	• ***Infrared (IR) technologies*** for target detection, e.g.:		Air Force
	– Space-Based Infrared System (SBIRS) -High	EMD	
	– SBIRS-Low	Dem/Val	
	• ***Space-Based Radar (SBR) technologies***	Technology developments	Air Force (lead) DARPA, NRO, Army
	– Airborne moving target indication (AMTI)		
	– Ground moving target indication (GMTI)		
	– SBR with GMTI and SAR imaging (space-based sensor support to operations)		
	• ***Hyperspectral Imaging (HSI) projects*** to address HSI utility issues:	Technology demonstrations	
	– Warfighter I		Air Force
	– EO-1		NASA
	– Multispectral Thermal Imager (MTI)		DOE
	• ***Space-Based Laser (SBL) Imaging***	Concepts, experiments, developments	Air Force
	– Lighter, cheaper, stable, large space optics		
	– On-orbit resupply concepts		
	• ***Space Maneuver Vehicle (SMV)***	System concept	Air Force
	– Tailored ISR constellations		
	– Interchangeable ISR payloads		
Platform Technologies	• ***Generic spacecraft projects***	Concepts, experiments, developments	(Several)
	– Radiation-hardening technology programs		
	– Processor development activities		
	– Battery development activities		
	– (See **SatOps** concepts and projects		
	– *(Other classified activities)*		
Information Management	• ***Real-time global awareness***	Concepts, experiments, developments	Government interagency activities (DoD, NASA, others)
	– Consistent battlespace picture		
	— To provide a common operational context		
	– Automatic target recognition (ATR)		
	– Broadband crosslinks and downlinks		
	— To support data processing		
	– Tactical display feeds		
	— To disseminate ISR products and services		
	– Future information, fusion and dissemination architectures		
	– Information exploitation technologies		

DemVal Demonstration/Validation acquisition phase EMD Engineering and Manufacturing Development phase

Opportunities for Partnering

The DoD, DOE and NASA Space Technology Alliance (STA) coordinates development of affordable technologies with applications to space.

The National Security Space Architect (NSSA) is developing, coordinating and integrating DoD and IC space architectures. Meanwhile DoD, civil and commercial systems need to be integrated to achieve required capabilities at affordable cost, to include:

- Integration of NRO sensor and communications systems in theater operations
- Cooperation with other agencies, such as NOAA for weather satellites
- Coordination among Service space activities
- Finding best ways to use commercial space capabilities.

Air Force work to make large space optics lighter, stable and cheaper may also benefit NASA and other space systems and concepts.

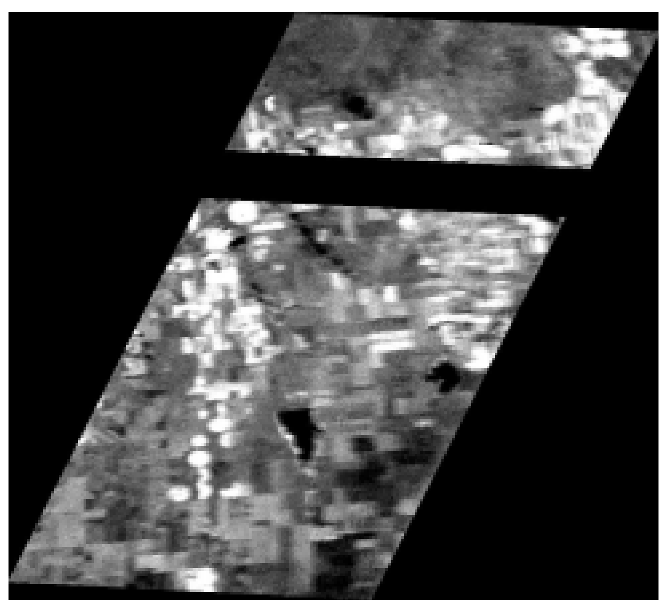
The DoD and IC are beginning to share the burdens of basic technology development and costs of the industrial infrastructure with commercial industry (e.g., the NRO is already using a commercial bus for some satellite systems). Lessons learned from mass manufacturing of commercial satellites will benefit both government and industry.

In the area of commercial remote sensing, NIMA acquires commercial imagery from multiple vendors both for geospatial data production and for peacetime and crisis applications. NIMA will also acquire unclassified imagery from new high-resolution commercial remote sensing systems with enhanced spectral capabilities. A joint government-industry team will identify the best data acquisition approach for the future.

Meanwhile, broadband demands of an SBR system and similar anticipated commercial systems may result in a very difficult frequency allocation challenge. Here, the DoD should use commercial industry's influence in the international arena to achieve common solutions.

MightySat II.1 Fourier Transform Hypersepectral Imager (FTHSI):
First Image From Space (Georectified)

False Color IR Image (3 bands)



Grayscale Image (λ =775)

14. Summary

Approach and Activity

Pursuant to §1601 of the *National Defense Authorization Act* for FY 2000, the DoD has developed this Space Technology Guide. Its overarching objective is to:

- Research and identify enabling technologies that will support emerging defense space systems and missions during the next 20 years and beyond
- Identify those space-relevant technologies that "must be done and must be done right" to preserve our national security space preeminence well into the 21st century.

The STG's time frame covers the next 20 years, to about 2020, from the perspective that, just as our current space capabilities have resulted from technologies developed in decades past, our future capabilities will depend on the technologies under development now. Moreover, for the U.S. to prevail in a world that is increasingly moving both commercial and military functions to space, the DoD needs to emphasize the development of those technologies that will provide the most leverage in meeting national security space objectives.

In first identifying and then selecting the many space-relevant technologies under way or planned, we:

- Referred to top-level defense space planning community documents for their perspectives on operational needs, concepts and technologies for the future
- Researched the S&T community's documents for requisite technology projects within both DoD and other Federal government agencies
- Solicited views and initiatives from the space industry
- Identified technology areas and projects being pursued via interagency collaboration.

Special attention has also been paid to two areas of Congressional interest:

- Microsatellite technologies, which have emerged from the preexisting trend towards miniaturization of components and spacecraft
- Space technology demonstrations, which have been increasing in relative cost and declining in frequency, and which are now dependent largely on other programs' launch opportunities or room on the Space Shuttle to be launched into space.

Findings and Observations

- There is an extensive number of enabling technologies, covering much of the S&T spectrum, that contribute to the continuing preeminence of U.S. national security space capabilities. A few of these technologies are exclusive to space applications, but most comprise the extensive menu from which terrestrial as well as space applications are continually being made. With varying emphasis and often in partnership with other Federal agencies and the private sector, they are the space-relevant technologies in which the Department invests the major part of its research and advanced technology resources.
- Of this large number, a select list represents cross-cutting technologies that not only support multiple mission areas but do so in ways that promise major advances in capability over a relatively short time — to the extent that they represent the possibility of breakthroughs to new levels of capability or system effectiveness, thus amplifying their return on investment. These have been identified as **key enabling technologies** (and are listed on p. 14-2).
- Based in part upon information provided by representatives of the space industry, some technologies are government-unique and some others are not commercially viable. If such technologies are to be developed and applied, then the government must provide the investment. For example, many sensor applications are unique to government requirements and hence are funded solely by the government. Similarly, there are additional technologies that are essential for government missions but which may have or develop commercial application as

Key Enabling Technologies

- **Propulsion / Propellants**
  - Advanced cryogenic
  - Full flow cycle
  - Advanced solid rocket motors (SRMs)
  - Combined-cycle (air-breathing engines + rocket)
  - Electric (Hall effect, ion, plasma thrusters)
  - Solar thermal/chemical
  - High-energetic, low-hazard, non-toxic, storable propellants
- **Electric Power**
  (Solar / Chemical / Mechanical; i.e., cells/batteries/flywheels)
  - Higher energy density and efficiency
  - Longer life, higher duty cycle
  - Lightweight, thermally stable
- **Structures and Materials**
  - Lightweight, high-strength composites and ceramics
  - Multi-functional, adaptive structures
  - Processing techniques
  - Vibration and thermal control
  - Thin films and environmentally protective coatings and insulation
- **"Thinking" Satellites**
  - Autonomous control
  - Self-assessment/correction
  - Threat detection
  - On-board supercomputing
  - On-orbit robotics
- **More Precise Clocks / Time Sources**
  - Laser/optical, atomic
- **Communications**
  - Lasercom
  - Wideband microwave/millimeter wave
- **Antennas**
  - Large, light, controllable, adaptive space-time
  - Higher frequency
  - Steerable beam phased arrays
  - Higher-efficiency amplifiers
- **Synthetic Aperture Radar (SAR)**
  - Large, light, high-power
  - Interferometric
- **Electro-optic (EO) Sensors**
  - Large, light, deployable, stable, adaptive optics
  - Multi-, hyper- and ultraspectral
  - Large-scale, high-quality focal plane arrays (FPAs)
  - Light, long-life, high-efficiency cryocoolers
  - Uncooled sensing materials
- **Signal Processors (Transmitters / Receivers)**
  - Higher signal-to-noise ratio
  - Higher density devices and circuitry
  - Higher efficiency analog-to-digital (A/D) conversion
  - Advanced encryption technologies
- **Microelectromechanical Systems (MEMS) / Microelectronics / Photonics**
  - Switches and actuators
  - Gyroscopes (e.g. fiber-optic gyros)
  - Inertial measurement units (IMUs)
  - Accelerometers
  - Non-volatile logic and memory
  - Opto-electronics
- **Radiation Hardening**
  - Techniques and components
  - Memory, processors, semiconductor materials
- **Ground Processing**
  - Data fusion
  - Advanced algorithms for processing and exploitation

While these key enabling technologies represent a general focus for Department activity and are deemed prerequisite to far-term space preeminence, they should not be pursued at the expense of the wide range of S&T work that is conducted across the DoD components — much of which has not been specifically identified in this Guide but which also represents important space potential at varying stages of maturity.

well; however, the cost of their development is usually so high that industry cannot make a business case for maturing them commercially. Examples include the Global Positioning System, or development of new propulsion concepts. (These private sector views were also considered in identifying the key enabling technologies.)

- The notion of partnerships must be viewed, considered and applied with care. Intra-government partnerships have usually worked well. With the emergence of the Space Technology Alliance; the Air Force Space Command, National Reconnaissance Office and National Aeronautics and Space Administration Partnership Council; and the brokering of partnerships by the Space Test Program, the government has fostered numerous highly productive collaborations that have minimized duplication and leveraged joint resources. Industry/government partnerships have had less success as the latter is driven primarily by national policy considerations while the former is driven by economic market forces. Again, national security space requirements are often unique, while the business case for industry has been risky at best. Typically, the most effective industry-government partnerships have been in areas like launch vehicle propulsion, spacecraft bus and spacecraft propulsion technologies, where companies can readily leverage the joint investment into their commercial market segments and strategic plans. From the DoD perspective these activities have best been fostered by coordinated government/industry-funded programs like the Integrated High Payoff Rocket Propulsion Technology program (IHPRPT).

- The short-term payoffs of the investments in microsatellite technologies will be seen in the application of miniaturization to existing systems to enhance performance and/or capability. For example, smaller lighter components may translate into more fuel for longer life on orbit. Such benefits are immediate and achievable in the near-term. Over the longer term, we expect to see significant microsatellite contributions in special-purpose and "niche" roles, to include enabling new operational capabilities of major significance and cost-effectiveness. For example, a microsatellite or microsat constellation could enhance revisit times and augment imagery of a specific geographic area during a contingency situation. However, the broad application of microsatellites to the full range of national security missions is unlikely even in the far term. Some limitations imposed by the laws of physics will require larger platforms for the foreseeable future.

- Of major concern: space-based technology demonstrations are expected to continue to decline due primarily to budgetary constraints. Major experiments and demonstrations are typically expensive, even when the launch segment costs are manageable. Military science gets to orbit when other major missions (such as missile defense) represent the prime payload and bear the bulk of the costs. Otherwise, experiments must either be tested on the ground (which has significant limitations and risks), be subject to the attrition of budget priorities, or be cancelled when no longer considered priority candidates for limited funding.

The STG itself provides an unconstrained approach via its focus on technology projections well beyond the FYDP, but it is not in a position to address

Space Orbit Transfer Vehicle (SOTV)
High energy transfer vehicle

funding and budgetary implications for the next 20 years. While increased funding of many promising areas could accelerate the possibilities for success, specific S&T breakthroughs cannot be guaranteed by money alone. Instead, a balanced and steadily supported S&T program provides the greatest likelihood of success and flexibility in advancing defense space capabilities.

Collected Recommendations

1. Continue to pursue a balanced S&T program to provide the breadth and flexibility to support a wide range of space technology applications to meet current and emerging needs.
   - Continue to incorporate private sector advances where appropriate in pursuit of this broad S&T program so as to leverage government applications from a broader commercial base.
   - Continue to miniaturize components so as to lower launch costs, extend on-orbit life, upgrade replacement satellite performance, enable new capabilities for satellites of all sizes, and develop new operational paradigms.
   - Sustain investment in advanced technologies to increase reliability, durability, and payload flexibility and reconfigurability.
   - Pursue microsatellite concepts via experiments and demonstrations keyed to proving the component technologies and demonstrating military utility.
2. Focus enough government resources on the key enabling technology areas identified above to assure their timely availability for system and operational applications.
   - Leverage private sector technology investments where possible, but recognize that there are areas where national security applications require unique features and capabilities, and that the government must take the lead in their development.
   - Recognize that, for such cross-cutting technologies to be available when needed, focused but stable investment is required as a prevailing condition.
3. To facilitate technology transition, continue to structure and budget for space experiments and demonstrations as a key part of requisite technology application, maturation, and proof of military utility.
   - Recognize that experiments and demonstrations represent long-lead, risk-reduction opportunities prior to full-scale development and application, which otherwise could be even more risky and costly.
   - Collaborate where practical via partnerships to share costs and broaden the basis for support.

Conclusion

The relationships of the operational space community's projected space missions and functions and the S&T community's space-related technology activities are depicted in the two-page illustration on pages 14-5 and -6. From the left of page 14-5, operational needs, emanating from Joint Vision 2010/2020, have been implemented in USSPACECOM's *Long Range Plan* for 2020. From the right of page 14-6, the space technology base illustrates the S&T documentary progression from basic research through successive development stages, to include interaction with the operational and acquisition communities, both to tailor technological effort to operational needs and to assure that needs are attainable and affordable. The area of convergence is at the Departmental level, where, to meet STG objectives, technology-dependent space missions help to define the key technologies that will enable the successful performance of their future functions. If pursued with well-planned and sustained investment, their projected effectiveness and synergies will do much to achieve our national security space objectives for at least the first half of the 21st century.

DoD Space Technology

OPERATIONAL NEEDS

JOINT VISION 2010 and 2020

CONCEPTS

DOMINANT MANEUVER
+
PRECISION ENGAGEMENT
+
FULL DIMENSIONAL PROTECTION
+
FOCUSED LOGISTICS

FULL SPECTRUM DOMINANCE

JOINT WARFIGHTING CAPABILITY OBJECTIVES

1. Information Superiority
2. Precision Force
3. Combat Identification
4. Theater Missile Defense
5. Military Op'ns in Urban Terrain
6. Joint Readiness
7. Joint Countermine
8. Electronic Warfare
9. Information Warfare
10. Chem/Bio Agent Detection
11. Real-Time Logistics Control
12. Counter-proliferation

USSPACECOM VISION (LRP for 2020)

CONCEPTS-Objectives–Tasks

CONTROL OF SPACE

- Assured Access -
– Transport Mission Assets –
– On-Orbit Operations –
– Service and Recovery –

- Surveillance of Space -
– Detect (all) –
– Track (all) –
– Characterize (all) –
– Classify (threats) –
– Catalog/Monitor (sats) –
– Disseminate/Distribute –

- Protection -
– Detect & Report Threats/Attacks –
– Withstand & Defend –
– Reconstitute & Repair –
– Assess Mission Impact –
– Identify, Locate & Classify (threat/attack sources) –

- Prevention -
– Detect Use (of systems) –
– Assess Mission Impact –
– Timely/Flexible Reaction –

- Negation -
– Target Identification –
– Weaponeering –
– Operations Cycle –

GLOBAL ENGAGEMENT

- Integrated Focused Surveillance -
– C4ISR –
– Detecting, Cueing, Fusing –
– Warning (of threats) –
– Tasking –
– Classifying, Characterizing, Discriminating –
– Monitoring, Cataloging, Assessing–
– Tailoring (products to needs) –
– Dissemination (of support) –

- Missile Defense -
– Battle Management –
– On-Demand Missile Defense –
– Full Spectrum Engagement –
– Combat Assessment –

- Force Application -
– BMC3 –
– On-Demand Force Applic'n –
– Flexible Force Application –
– Flexible Effects –
– Combat Assessment –

FULL FORCE INTEGRATION

GLOBAL PARTNERSHIPS

CRITICAL SPACE TECHNOLOGY

DoD SPACE TECHNOLOGY GUIDE

TECHNOLOGY AREA NEEDS

KEY FUNCTIONS

SPACE TRANSPORTATION

SATELLITE OPERATIONS

NAVIGATION

COMMAND, CONTROL, and COMMUNICATIONS

ENVIRONMENTAL MONITORING

INTELLIGENCE, SURVEILLANCE, and RECONNAISSANCE

SPACE CONTROL
- Surveillance of Space
- Protection
- Prevention
- Negation

FORCE APPLICATION
- Deterrence
- Defensive
- Offensive

KEY ENABLING TECHNOLOGIES

(Must Do Right, and In Time)
DoD-unique, or DoD as lead

PROPULSION / PROPELLANTS

ELECTRIC POWER (Solar / Chemical / Mechanical)

STRUCTURES and MATERIALS

"THINKING" SATELLITES

PRECISE CLOCKS / TIME SOURCES

COMMUNICATIONS

ANTENNAS

SYNTHETIC APERTURE RADAR (SAR)

ELECTRO-OPTIC (EO) SENSORS

SIGNAL PROCESSORS (Transmitters / Receivers)

MICROELECTRO-MECHANICAL SYSTEMS (MEMS) / MICRO-ELECTRONICS / PHOTONICS

RADIATION HARDENING

GROUND PROCESSING

Guide: Document Flow

TECHNOLOGY BASE

DEFENSE SCIENCE AND TECHNOLOGY STRATEGY
Interaction of Documentation

JWSTP (2000)	←**(DTOs 2000)**→	**DTAP (1999)**	**BRP (1999)**
JWCOs (across the JWCAs)	2-letter DTOs for DTAP Panels 1-letter DTOs for JWSTP Panels (Cross-refs = Mutual Support)	DTAP Panels (+ the BRP Panel)	S&T Fields (20-year payoff)
PROTECTION OF SPACE ASSETS **Space Protection**	**SP.**01, 03, 05 → ← **N.**01, 02, 03, 04 **SP.**08, 22 → **SP.**10, 11, 20 →	**SPACE PLATFORMS (Subpanels)** – Space Vehicles and Launch Vehicles – – Propulsion –	**PHYSICS** – Radiation – – Matter & Materials – – Energetic Processes – – Target Acquisition –
+ **Space Protection-Related**	← **A.**13, (**A.**28) ← **NT.**01, 02, ← **NT.**05, 06, 09 **MP.** 29.01 → ← **SE.**37, **SP.**20	**MATERIALS/PROCESSES** – Materials & Processes for Survivability, Life Extension, & Affordability –	**CHEMISTRY** – Materials Chemistry – – Chemical Processes –
+ **Surveillance of Space**	← **D.**03, 05 ← **HS.**06, 13, 21, ← **HS.**23, 28 **NT.**02, 05, 06 → ← **SE.**33, 38, 58, **NT.**01 → ← **SE.**59, 61, 65, 67	**NUCLEAR TECHNOLOGY** – System Effects & Survivability – – Test & Simulation Technology –	**MATHEMATICS** – Modeling & Math'l Analysis – – Computational Mathematics – – Stochastic Analysis & Operational Research –
+ **Prevention** **+** **Negation**	← **IS.**38, 50 **SE.**37, 38, 55 → ← **WE.**22, 41, 43 **SE.**56 = **BE.**06 →	**SENSORS, ELECTRONICS, & BATTLESPACE ENVIRONM'T** – RF Components – – Microelectronics – – Electronic Materials –	**COMPUTER SCIENCES** – Intelligent Systems – – Software – – Architecture & Systems –
INFORMATION SUPERIORITY – Global Battlespace Awareness – – Effective Force Employment – – C4ISR Grid –	**WE.**21 → ← **A.**06, 07 **WE.**41 → ← **A.**11, 13	**WEAPONS** – Conventional – – Directed-Energy Weapons – **INFORMATION SYSTEMS TECHNOLOGY**	**ELECTRONICS** – Solid-State & Optical Electronics – – Information Electronics – – Electromagnetics –
JOINT THEATER MISSILE DEFENSE	← **D.**03, 05, 08 **IS.**23, 38 →	– Seamless Communications – **AIR PLATFORMS**	**MATERIALS SCIENCE** – Structural Materials – – Functional Materials –
FORCE PROJECTION/ DOMINANT MANEUVER	← **G.**12	**GROUND & SEA VEHICLES**	
JOINT READINESS & LOGISTICS, and SUSTAINMENT OF STRATEGIC SYSTEMS	← **K.**01, 02, 06	**CHEMICAL/BIOLOGICAL DEFENSE TECHNOLOGY** **BIOMEDICAL**	**MECHANICS** – Solid & Structural Mechanics – – Fluid Dynamics – – Propulsion & Energy Conversion –
COMBAT IDENTIFICATION **PRECISION FIRES** **ELECTRONIC WARFARE**		**Plus:** **BASIC RESEARCH Panel**	**TERRESTRIAL SCIENCES** **OCEAN SCIENCES**
MILITARY OPERATIONS IN URBANIZED TERRAIN **COMBATING TERRORISM** **CHEM/BIO WARFARE DEFENSE & PROTECTION, and COUNTER-WMD** **HARD & DEEPLY BURIED TARGET DEFEAT**	*These "DTO-2000" space-related technologies represent a "snapshot" of currently active listings and their primary JWCO/DTAP panel associations. Many additional technologies (both mature and developmental) may also be applied to support national security space objectives*	– Physics – – Chemistry – – Mathematics – – Computer Sciences – – Electronics – – Materials Science – – Mechanics – – Terrestrial Sciences – – Ocean Sciences – – Atmospheric & Space Sciences – – Biological Sciences – – Cognitive & Neural Science –	**ATMOSPHERIC & SPACE SCIENCES** – Meteorology – – Remote Sensing – – Space Science – **BIOLOGICAL SCIENCES** **COGNITIVE & NEURAL SCIENCE** – Reverse Engineering –