CHAPTER VIII
SPACE PLATFORMS

A. INTRODUCTION

This chapter represents a significant advance in the Defense Reliance Program because for the first time the space warfighters and other federal space agencies have directly participated in the DTAP preparation. United States Space Command, Air Force Space Command, and the National Reconnaissance Organization (NRO) have all contributed to this chapter. This chapter is not only a coordinated S&T plan for Space Platforms within DoD, but also the beginning of a coordinated federal S&T plan for Space Platforms across DoD, NASA, and the NRO.

In 1997, DoD, NASA, and the NRO created the Space Technology Alliance (STA) to "coordinate the development of affordable, effective space technologies for the greatest return on government funds." The STA is making steady and significant progress in coordinating government S&T investment in space and has developed a prototype methodology for categorizing space technologies. This prototype methodology is called the Space Technology Inventory (STI) and is contained in Table VIII–1. The STI will change as the tools required for coordinating DoD, NASA, and the NRO planning become better understood and in future years may look very different from that in Table VIII–1. The STI does not currently cover all federal space-related S&T (e.g., it does not include S&T for human space activities), but rather only those S&T areas where DoD, NASA, and the NRO all have current interest. It does cover all the areas where DoD currently has interests. Since DoD, NASA, and the NRO are not making an S&T investment in all of the technology areas in Table VIII–1, those areas where DoD is making an S&T investment are indicated.

Within DoD, responsibility for the technologies in Table VIII–1 is allocated to several DTAP panels. Table VIII –1 also maps the STA's STI into the DTAP.

To facilitate NASA and the NRO understanding of DoD Space Platforms S&T information, this chapter adheres to the terminology used in Table VIII–1. The NASA and NRO counterparts to this chapter are the NASA Technology Plan and the NRO Technology Roadmaps.

1. Definition and Scope

The Space Platforms technology area is focused on efforts devoted to the core functions needed in space and launch vehicles. This generally encompasses the STA technology areas of integrated spacecraft systems technology, autonomy, space vehicles technology, and launch and transfer. Space Platforms also includes the specific STA technologies of debris and contamination. The panel develops technologies for the three segments of a complete space system: the launch segment, the space segment, and the ground segment.

Table VIII–1. STA Space Technology Inventory

Technology Area	DoD Investment	DTAP
Integrated Spacecraft Systems Technology		
Systems Analysis & Design Methods	X	Space Platforms
Advanced Concept Definition	X	Space Platforms
Standardization		Space Platforms
Advanced Integration & Test Methodology	X	Space Platforms
Demonstrations (Space & Ground)	X	Space Platforms
Autonomy		
On-Board Autonomy	X	Space Platforms
Mission Operations	X	Space Platforms
Advanced Methods		Space Platforms
Space Vehicles Technology		
Structures		
Structural Controls & Dynamics	X	Space Platforms
Multifunctional Structures	X	Space Platforms
Materials	X	Materials/Processes (a)
Thermal Management		
Controls & Materials	X	Space Platforms
Conventional Cooling	X	Space Platforms
Cryogenic Cooling	X	Space Platforms
Heaters		Space Platforms
Command & Control		
Guidance, Navigation & Control	X	Space Platforms
Astrodynamics & Geodesy	X	Space Platforms
Attitude Determination & Control	X	Space Platforms
Radio Navigation	X	Space Platforms
Command & Data Handling	X	Space Platforms
Telemetry, Tracking & Control	X	Space Platforms
Ground Stations	X	Space Platforms
Satellite Software Architecture	X	Space Platforms (b)
Multisatellite Communications	X	Electronic Warfare
Electronics		
Flight Computers & Components	X	Electronic Warfare
Microelectronics	X	Electronic Warfare
Photonics	X	Electronic Warfare
Rad-Hard Technologies	X	Electronic Warfare
Survivability & Vulnerability		
Threat Warning & Attack Reporting	X	Space Platforms
Protective Technologies	X	Space Platforms
Self-Protective Modes	X	Space Platforms
Manmade Radiation	X	CB Defense (c)
Aerothermodynamics	X	CB Defense (c)
Onboard Propulsion		
Chemical	X	Space Platforms
Electrical	X	Space Platforms
Space Power		
Energy Production	X	Space Platforms
Energy Storage	X	Space Platforms
Distribution & Conditioning	X	Space Platforms

Table VIII–1. STA Space Technology Inventory (cont'd)

Technology Area	DoD Investment	DTAP
Sensors		
Detection		
Microwave/Millimeter Wave	X	Sensors
Radar	X	Sensors
Lidar	X	Sensors
Infrared	X	Sensors
Ultraviolet/Visible	X	Sensors
Multi- & Hyperspectral	X	Sensors
Optics		
Adaptive	X	Sensors
Segmented	X	Sensors
Arrays	X	Sensors
Instrument Systems	X	Sensors
Communications		
Radio Frequency		
Sources	X	Electronic Warfare
Electronic: MMICs, LNAS	X	Electronic Warfare
Antennas: Adaptive, Arrays, Multibeam	X	Electronic Warfare (d)
Laser		
Sources	X	Electronic Warfare (d)
Optics	X	Electronic Warfare (d)
Detectors	X	Electronic Warfare (d)
Architectures & Networks		
Network Management		Electronic Warfare
Protocols/Interoperability		Electronic Warfare
Link Hardening		Electronic Warfare (d)
Space Environment		
Solar	X	Basic Research
Deep Space	X	Basic Research
Debris & Micrometeorites	X	Space Platforms
Upper Atmosphere		
Neutral Species Density	X	Basic Research
Ionospheric Characterization	X	Basic Research
Total Electron Content	X	Basic Research
Electronic Profiles	X	Basic Research
Local Plasma Effects	X	Basic Research
Contamination (i.e., outgassing)	X	Space Platforms
Special Ground Simulation Facilities	X	(e)
Optical Backgrounds	X	Sensors
Information Systems Technology		
Intelligent Systems & Networks	X	Info Systems Tech
Human–Computer Interfaces	X	Human Systems
Advanced Computing Concepts Mission Data	X	Info Systems Tech
Processing & Exploitation		
Onboard Processing	X	(e)
Ground Processing & Exploitation	X	(e)
Image Processing	X	(e)
Signal Processing		(e)
Data Fusion	X	(e)

Table VIII–1. STA Space Technology Inventory (cont'd)

Technology Area	DoD Investment	DTAP
Launch & Transfer		
Propulsion		
Chemical	X	Space Platforms
Electric	X	Space Platforms
Nuclear		(f)
Advanced Concepts	X	Space Platforms
Vehicles		
Structures & Materials	X	Space Platforms
Aerothermal	X	Space Platforms
Guidance & Control	X	Space Platforms
Systems (batteries, actuators, etc.)	X	Space Platforms

(a) Generic development by Materials/Processes, adapted for space use by Space Platforms.
(b) New techniques by Information Systems Technology, adapted for space use by Space Platforms.
(c) Generic development by CB, adapted for space use by Space Platforms.
(d) Generic development by Electronics, adapted to space environment by Space Platforms.
(e) Developed by each DTAP panel as required.
(f) DOE responsibility.

The Space Platforms panel is subdivided into the two subpanels of space/launch vehicles and propulsion as depicted in Figure VIII–1. Space vehicles refer to the spacecraft bus (as opposed to the entire spacecraft, which includes both the bus and the mission payload). Launch vehicles include all of the lift vehicle, except the engines. Included in this subarea are ballistic missile technologies. This subpanel is also responsible for ground segment technologies. The propulsion subpanel is responsible for the boost, orbit transfer, and spacecraft propulsion efforts of the DoD Integrated High-Payoff Rocket Propulsion Technology (IHPRPT) program. The subpanel also manages the solid-rocket motor efforts of IHPRPT for Sustainment of Strategic Systems in the JWSTP, as the technologies are directly applicable to space launch systems.

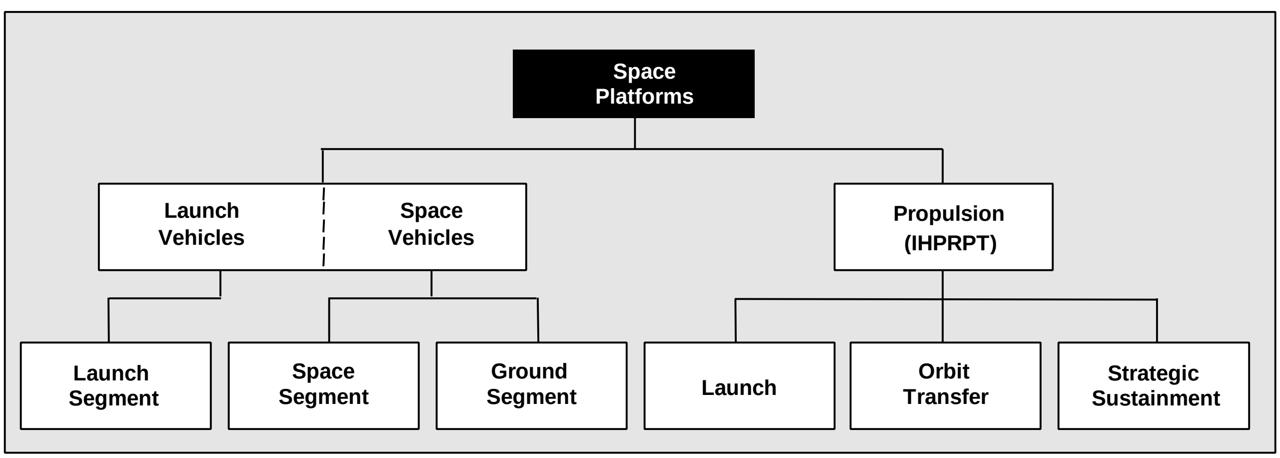

Figure VIII-1. Planning Structure: Space Platforms Technology Area

Space Platforms technology interfaces with other DTAP and JWSTP areas impacting overall space system capability, including Information Systems Technology; Materials/Processes; Sensors, Electronics, and Battlespace Environment; Weapons; and Sustainment of Strategic Systems. Technologies in these areas that are unique to space and launch vehicles are presented in their respective chapters, but they are referenced in this chapter for completeness.

2. Strategic Goals

The overarching strategic goal for Space Platforms is to maintain U.S global superiority in space while making space access and operations easily affordable. From space, a whole range of critical information collection and distribution functions become possible with both robust global reach and little forward-based infrastructure. Information provided to U.S. military personnel by space-based systems includes weather, forces location/movement, environmental monitoring, transportation routes, advanced warning on weapons deployment, and weapons targeting. Future space systems could allow application of space-based force against ballistic missiles and other threats. The number of space-faring nations and their capabilities is increasing and, with that, the threat possibility to U.S. forces. Space systems based on current technology are highly expensive to acquire and operate. This high cost threatens U.S. dominance of space and drives subarea goals.

Reducing the costs of future space systems can be most affected by reducing weight and manpower, which are pervasive life-cycle cost factors in space systems. The primary goal for the launch vehicles subarea is to reduce the cost per pound for delivering payloads to their required orbits. A reduction in turnaround time between launches is also a goal. The goals for the space vehicles subarea are to construct spacecraft that are lighter, are smaller, require less power, and have a longer functional lifetime with lower life-cycle costs while maintaining and improving overall system performance and operation. Achievement of these goals is grounded in the basic technologies of structures; power; thermal management; guidance, navigation, and control (GN&C); electronics; survivability; and satellite control. Due to the demands of space flight, new space vehicle technologies must be demonstrated in a suitable environment before they can be incorporated into operational systems. Space propulsion subarea goals are focused on development of rocket propulsion engines and motors with improved performance for transition into existing or new systems. Boost and orbit transfer propulsion systems will demonstrate improvements in specific impulse, mass fraction, thrust to weight, reliability, reusability, and cost. Spacecraft propulsion systems will demonstrate improvements in specific impulse, thruster efficiency, and mass fraction. Achieving space platform goals will enable key technology transition/transfer opportunities as shown by subarea in Table VIII–2.

3. Acquisition/Warfighting Needs

a. *Warfighting Needs*[1]

DoD is required by National Space Policy to maintain the capability to execute the space mission areas of space support, force enhancement, space control, and force application. These

[1] Written by United States Space Command (USSPACECOM/J5R).

Table VIII–2. Space Platforms Technology Transition Opportunities

FY 2000	FY 2005	FY 2010
LAUNCH VEHICLES SUBAREA		
RLV Reusable LH2 Tank Payload Shroud Cryo Propellant Tank	*RLV* SSTO LV Structure	
ELV and Strategic Sustainment Integrated Measurement Unit Components Multiuse Battery	*ELV and Strategic Sustainment* Long-Life Inertial Guidance Units Post-Boost Control System Material Update	*ELV and Strategic Sustainment* Missile Aging and Surveillance Predictions for Individual Motors
Upper Stage/OTV Chemical/Solar Thermal Propulsion	*Upper Stage/OTV* Autonomous Navigation	*Upper Stage/OTV* Propulsion Life-Cycle Surveillance High-Efficiency Control System
SPACE VEHICLES SUBAREA		
Space Structures & Control Fiber Optic Sensors Passive Lateral Axial Isolation	*Space Structures & Control* Passive Lateral/Active Axial	*Space Structures & Control* Hybrid Axial Isolation
Cryogenics Reverse Brayton Cooler	*Cryogenics* Microcooler	*Cryogenics* Laser Cooler
Satellite Control On-Board Health & Status Assessment Satellite-Initiated Ground Contacts Partially Autonomous Mission Data Processing	*Satellite Control* Intersatellite Cooperation	*Satellite Control* Onboard Anomaly Resolution Autonomous Mission Operations
Space Power Systems NiH_2 Batteries Double-Junction Solar Cells	*Space Power Systems* Li Ion Batteries Triple-Junction Solar Cells	*Space Power Systems* Flywheel Storage Solar Dynamic Systems
Thermal Management Loop Heat Pipes	*Thermal Management* Carbon-Carbon Radiator	*Thermal Management* Capillary Pumped Loops
SPACE PROPULSION SUBAREA		
RS–27 Upgrade EELV Tech Insertion Titan SRMU Solar Electric Propulsion	Environmentally Clean Motors Russian Engine Tech Reusable Cryo Engine Shuttle Replacement	Rapid Response ELV Improved Russian Engine Tech Trans. Atmospheric Vehicle

mission areas are assigned to USSPACECOM for execution. Within these four mission areas, USSPACECOM conducts the following missions as directed by the Unified Command Plan (UCP): space launch and space system control; intelligence, surveillance, and reconnaissance (ISR); communications (MILSATCOM); navigation; environmental monitoring (METOC); command and control; threat warning/attack reporting; space surveillance and battle management command, control, communications, computers, and intelligence (BM C^4I); space system prevention; ballistic missile defense; aerospace defense; and power projection.

Today, the United States is the preeminent military power in space. Dominating the space dimension of military operations to protect U.S. interests and investments in space, as well as integrating space forces into warfighting capabilities across the full spectrum of conflict, is the desired end state. In order for USSPACECOM to meet its directed UCP missions, it has identified, through its long-range plan, four main operational concepts:

- *Control of Space*. The area of space is evolving into an economic and military "center of gravity" for the United States. As our dependence on space increases, so does our vulnerability. As a result, we must be able to protect our space assets across a wide variety of possible adversary actions. Control of space is comprised of four "pillars": surveillance of space, protection, prevention, and negation.

- *Global Engagement*. This concept includes global surveillance of the Earth, worldwide missile defense, and the potential ability to apply force from space. The need to address the increasing threat from ballistic and cruise missiles and the ability to have increased forward presence with reduced forward basing is a high priority for U.S. senior leadership.

- *Full Force Integration*. The integration of land, sea, air, and space forces is a prerequisite to achieving full spectrum dominance as outlined in *Joint Vision 2010*. A key warfighting advantage of the future will be our increased ability to get the right information at the right time to the right warfighter and enable a more rapid response to an enemy.

- *Global Partnerships*. In the future, U.S. military space capabilities will be augmented by leveraging civil, commercial, and international space systems. Fiscal realities emphasize the need for closer military, civil, and commercial cooperation in developing our future warfighting capabilities. These partnerships will allow us to bolster our capabilities while simultaneously controlling costs.

As the nation and DoD move into the 21st century, space forces will continue to provide support from space and conduct space operations in support of the other warfighters. The emerging synergistic relationship of space with land, sea, and air will enable the United States to achieve full spectrum dominance on the battlegrounds of the future. USCINCSPACE will need the following capabilities to dominate space and integrate space power throughout military operations:[2]

- Real-time surveillance of space
- Timely and responsive spacelift
- Enhanced protection for military and commercial systems
- Flexible negation and prevention systems
- Nonintrusive surveillance of Earth from space
- National missile defense
- Enhanced command and control (C^2)
- Enhanced sensor-to-shooter capabilities

[2] Additional information regarding warfighter space needs and candidate technologies can be found in the USSPACECOM Long Range Plan located at website www.spacecom.af.mil.

- Battle manager—the ability to have common protocols, communications standards, and fused databases
- Precise modeling and simulation of space systems
- Capability to rapidly share space-based information within a comprehensive space systems architecture
- Ability to influence space systems design.

b. *Acquisition Needs*[3]

The military services through Air Force Space Command (AFSPC)/14th Air Force, Naval Space Command, and U.S. Army Space Command provide USSPACECOM with the systems and personnel to carry out space-based missions. The Space Platforms technology area must provide the military services with the new and improved launch and space vehicles technologies to support, expand, or enable all USSPACECOM missions. Lighter, stronger space vehicles must be developed to allow a step-down in launch vehicles or increased launch mass margin on current launch vehicles. For high-power geosynchronous Earth orbit (GEO) communications payloads, new technologies in space vehicles should be available to allow a launch vehicle step-down from the current heavy launch vehicle to an Atlas IIAS. Similarly, future technology developments should increase on-orbit life and reduce life-cycle costs. Additionally, space vehicles must be made more survivable against natural and manmade threats. The development of new propulsion systems, materials, avionics, production methods for launch vehicles, and reduced system costs should reduce the cost to low Earth orbit (LEO) from the current $7,000–$14,000/lb level to no more than $1,000/lb. In addition, the time between launches must be reduced from months to days.

B. DEFENSE TECHNOLOGY OBJECTIVES

	DTO	STI Area/Technology
Space Vehicles and Launch Vehicles Subpanel		
SP.01	Cryogenic Technologies	Space Vehicles/Thermal
SP.02	Thermal Management Technology	Space Vehicles/Thermal
SP.03	Space Structures and Control	Space Vehicles/Structures
SP.05	Large, Precise Structures	Space Vehicles/Structures
SP.08	Space Power System Technologies	Space Vehicles/Power
SP.22	Advanced Cyrogenic Technologies	Space Vehicles/Thermal
Propulsion Subpanel		
SP.10	Liquid Boost Propulsion/IHPRPT Phase I	Launch & Transfer/Prop
SP.11	Orbit Transfer Propulsion	Launch & Transfer/Prop
SP.20	Spacecraft Propulsion/IHPRPT Phase I	Space Vehicles/Onboard Prop

[3] Written in coordination with Air Force Space and Missile Center (SMC/XRT).

The following DTOs, not reported in this Space Platforms chapter, appear in the JWSTP and in other chapters of this document. They describe technology programs that contribute to the sustainment, expansion, or dominance of U.S. space systems.

Information Superiority Panel

A.06	Rapid Terrain Visualization ACTD	Info Sys Tech/Processing
A.07	Battlefield Awareness and Data Dissemination ACTD	Info Sys Tech/Processing
A.09	Semiautomated Imagery Processing ACTD	Info Sys Tech/Processing
A.11	Counter-Camouflage Concealment and Deception ACTD	Sensors/Detection (Radar)
A.13	Satellite C^3I/Navigation Signals Propagation Technology	Space Envirn/Upper Atmos

Joint Theater Missile Defense Panel

D.03	Discriminating Interceptor Technology Program	Info Sys Tech/Processing
D.05	Advanced Space Surveillance	Sensors/Detection
D.08	Atmospheric Interceptor Technology	Space Vehicles/Thermal

Force Projection/Dominant Maneuver Panel

G.12	Lightweight Airborne Multispectral Countermine Detection System ATD	Sensors Detection (Multispectral)

Sustainment of Strategic Systems Panel

K.01	Post-Boost Control System Technology	Launch & Transfer/ Aerothermal Veh
K.02	Missile Flight Science	Launch & Transfer/ Chem Propulsion
K.06	Missile Propulsion Technology	Launch & Transfer/ Chem Propulsion

Nuclear Technology Panel

NT.01	Nuclear Operability and Survivability Testing Technologies	Space Vehicles/Survivability
NT.02	Electronic System Radiation Hardening	Space Vehicles/Survivability
NT.05	Balanced Electromagnetic Hardening Technology	Space Vehicles/Survivability
NT.06	Survivability Assessments Technology	Space Vehicles/Survivability

Information Systems Technology Panel

IS.23	Digital Warfighting Communications	Communications/RF
IS.24	Multimode, Multiband Information System	Communications /RF
IS.38	Antenna Technologies	Communications /RF

Materials/Processes Panel

MP.29.01	Materials and Processes for IHPRPT	Launch & Transfer/ Chem Propulsion

Sensors, Electronics & Battlespace Environment Panel

SE.28	Low-Power RF Electronics	Space Vehicles/Electronics
SE.37	High-Density, Radiation-Resistant Microelectronics	Space Vehicles/Survivability
SE.38	Microelectromechanical Systems	Space Vehicles/Electronics
SE.55	Space Radiation Mitigation for Satellite Operations	Space Vehicles/Survivability
SE.56	Satellite Infrared Surveillance Systems Backgrounds	Space Envirn/Backgrounds

Weapons Panel

WE.21	Fiber-Optic, Gyro-Based Navigation Systems	Space Vehicles/C^2
WE.41	Multimission Space-Based Laser	

C. TECHNOLOGY DESCRIPTIONS

Space vehicles and launch vehicles are managed by a single subpanel within the Space Platforms technology area. In many cases, technologies for space vehicles and launch vehicles are unique and, for that reason, they are discussed separately (Sections C1 and C2). The propulsion subarea is described in Section C3.

1. Launch Vehicles

a. Warfighter Needs[4]

The warfighter must have the ability to deploy, sustain, augment, and recover on-orbit space forces and assets in support of the ground mission. Space launch vehicles must provide this service in a reliable, responsive, and affordable manner.

As the current fleets of expendable heavy- (e.g., Titan IV) and medium-launch vehicles (e.g., Atlas, Delta) are exhausted, AFSPC will rely primarily on the evolved expendable launch vehicle (EELV). The medium-lift version of the EELV should be operational around 2002, followed by the first operational heavy-lift launch in 2003. AFSPC will also continue to evaluate how best to use commercially available spacelift (foreign or domestic).

Meanwhile, AFSPC will begin exploiting reusable launch capabilities to provide more responsive, less expensive access to space. AFSPC will leverage off NASA's development of the reusable launch vehicle (RLV) and other X-vehicle programs to develop, as early as 2003, space operations vehicle and space maneuver vehicle demonstrators. With current fiscal constraints, success of the Space Operations Vehicle (SOV) program will depend heavily on how effectively

[4] Written by Air Force Space Command (AFSPC/XPX).

critical technologies can be harvested from NASA efforts. A fully reusable SOV/SMV (Space Maneuver Vehicle) system might be made available in the 2010 timeframe.

Launch vehicle technologies provide assured and affordable access to space, enabling use of space-based ISR, moving target indicator (MTI), multi- and hyperspectral imaging, and BM/C^2. These space-based capabilities support the Joint Warfighting Capability Objectives of Information Superiority, Precision Force, Combat ID, Joint Theater Missile Defense, Chemical/Biological Warfare Defense and Protection and Counter Weapons of Mass Destruction, Force Projection/Dominant Maneuver, and Joint Readiness and Logistics and Sustainment of Strategic Systems.

b. ***Overview***

The DoD S&T efforts included in the launch vehicles subarea encompass the structures, aero/thermodynamics, guidance and control, and systems subareas listed in the Space Technology Inventory for launch vehicles plus recovery, robotics/docking, survivability, secondary payloads, and range operations, which are not included in the STI.

(1) Goals and Timeframes. The subarea goals, system payoffs, and timeframes for the launch vehicles technologies are listed in Table VIII–3. The goals and payoffs are shown for the ELV and RLV. The technologies and associated objectives required to achieve the space vehicles goals and payoffs are detailed in Table VIII–4.

Table VIII–3. Launch Vehicles Subarea Goals and Payoffs

	FY00		FY05	
Space Vehicles	**ELV**	**RLV**	**ELV**	**RLV**
Subarea Goals				
Mass Fraction	0.058	0.093	0.044	0.07
System Cost	$39M	$329M	$22M	$224M
Flts Between Referb	–	5	–	10
System Payoffs				
$/lb Mass Delivered	$3,500	$5,500	$2,000	$3,750
No. Transfers/Vehicle	–	–	–	–
Turnaround Time	–	50 days	–	25 days
No. Flts/Vehicle	–	150	–	200

(2) Major Technical Challenges. Major technical challenges for ELVs include development of lightweight, low-cost, composite structures and propellant tanks; low-cost, fault-tolerant avionics; launch environment mitigation technologies; and lightweight, low-cost, and high-power density batteries. Reusable launch vehicles will require major breakthroughs in structures, materials for "hot-structure" airframes, instrumentation systems for vehicle health management and component failure diagnosis, propellant handling components and systems, and modular component designs to facilitate rapid refurbishment or repair. Structure multifunctionality, or the ability of primary structure to perform secondary functions such as thermal protection or acoustic attenuation, will need to be expanded in order to enable single-stage-to-orbit dry mass fractions.

Table VIII–4. Launch Vehicles Subarea Technology Objectives

Year	Technology	Objectives[a]
2000	Structures	Reduced structural mass: ELV & RLV 40% Reduced structural cost: ELV & RLV 40% Reduced dynamic launch loads ELV & RLV: Lateral 5X, Axial 5X
	Aero/Thermal	RLV: increase high-temperature materials reusability: 400 cycles
	GN&C	ELV/strategic sustainment: gyroscopes with 0.01-deg/hr drift, 8-yr MTBF
	Recovery	RLV: recoverable mass of 90%
	Power	Increase primary battery cycling rate ELV & RLV: 10 cycles
	Range Operation	RLV: range turnaround time of 36 hr Strategic sustainment: NDE on solid rocket fuel
2005	Structures	Reduced structural mass: ELV & RLV 55% Reduced structural cost: ELV & RLV 55%
	Aero/Thermal	RLV: increase high-temperature materials reusability 500 cycles
	GN&C	ELV/strategic sustainment: gyroscopes with 0.01-deg/hr drift, 15-yr MTBF
	Recovery	RLV: recoverable mass of 95%
	Range Operation	RLV: range turnaround time of 24 hr Strategic sustainment: NDE on solid rocket fuel

[a]Using 1996 technology levels as baseline

(3) Related Federal and Private Sector Efforts.[5] Currently identified technology efforts include the USAF EELV, NASA X-33/RLV, Boeing Delta III, Lockheed Martin Atlas IIAR, OSC Pegasus, and several other private-sector startup programs to include teaming with foreign manufacturers (primarily the former USSR republics). The NRO does not develop launch vehicles.

c. *S&T Investment Strategy*

Space launch vehicle investment is directed toward reducing the cost of launch vehicles while improving performance, reliability, autonomy, availability, and reusability.

(1) Technology Demonstrations. At present, no technology demonstrations are uniquely associated with the launch vehicles subarea.

(2) Technology Development. *Structures.* This work is focused on the development of structures and structural control technology for DoD space launch and ballistic missile vehicles. Work on tankage for launch vehicles is now being included in this technology effort. Work on nozzles and cases for rocket systems is included under the space propulsion subarea. Structures for hypersonic vehicles are covered under Air Platforms (Chapter I); work on ground-based ballistic missile interceptors is covered under Weapons (Chapter X). This technology effort overlaps with space vehicle structures and space propulsion. The Lightweight, Low-Cost Composite Payload Shroud Program is developing a payload shroud using the same structural concept but on a much more complex shape subject to significantly different loads. The use of composite isogrid structures will reduce fairing and interstage manufacturing cost and weight, resulting in reduced cost of launching space payloads and the ability to launch heavier and larger payloads into a higher orbits. The increasing DoD need to reduce launch cost has led to a significant in-

[5] Written in coordination with the NRO. The NRO Office of Corporate Communications may be contacted at (703) 808–1198.

vestment increase in launch vehicle structural component and structural control technology. Programs are exploring active control, passive damping techniques, precision deployable orbital structures, and advanced mechanisms to reduce the structural load that space vehicles must survive during launch. Of greatest promise, especially to reuseable vehicles, are programs being initiated to study structure multifunctionality, or the integration of thermal protection and acoustic attenuation into primary structures.

Aero/thermodynamics. This effort is focused on aerodynamic loads and thermal heating to which a launch vehicle is subjected as it ascends through the Earth's atmosphere. RLVs are also subject to such stresses on descent. This technology effort overlaps with space vehicle thermal management but usually deals with stresses of higher magnitude and shorter duration than does space vehicles.

*Guidance and Control***.** This work addresses advanced science and technologies for launch from Earth. G&C encompasses space launcher and ballistic missile guidance, navigation, and control; command and data handling; and telemetry, tracking, and control. These technologies overlap space vehicle command and control but have to deal with much higher acceleration rates, occur just once per vehicle, and can involve safety issues.

*Recovery***.** Developing the capability to recover assets from space and return them to Earth or refurbish/repair on-orbit is the thrust of this work. NASA's Space Shuttle is the only current system with any recovery capability.

*Robotics/Docking***.** This focuses on developing technologies that enable autonomous docking procedures, remote materials, propellant transfer, etc.

Survivability. This addresses developing hardened components that are required to survive space launch environments.

Range Operations. This work focuses on safety, handling, and control technologies for segments of the launch vehicle system that do not fly but are directly tied to flight such as trajectory monitoring, command destruction, and range turnaround operations.

Secondary Payloads. This work focuses on the ability to piggyback secondary payloads to primary payloads at little extra cost. This capability currently exists on the European Space Agency’s Arianne vehicle.

(3) Basic Research. Basic research supporting the launch vehicle systems is leveraged from the space vehicle technology programs and from related federal, university, and commercial efforts.

2. Space Vehicles

a. *Warfighter Needs*[6]

Space vehicle technologies provide the key satellite components, such as communications, electronics, antennas, cryogenic coolers, station-keeping thrusters, solar arrays, and power supplies needed to operate space-based sensors for ISR, multithermal imaging, imaging, and BM/C^2.

[6] Written by Air Force Space Command (AFSPC/XPX).

These space-based capabilities support all of the Joint Warfighting Capability Objectives by providing global situational awareness and information dominance.

Advances in space vehicle technologies produce both increased capabilities and reduced life-cycle costs. Some of these technologies are militarily unique while others benefit all sectors of the space arena. The rapidly growing commercial space sector will provide tremendous opportunities for partnerships in the development of new space vehicle advances.

Potential warfighting applications such as the Space-Based Laser will only occur with advances in large-scale lightweight structures, high-energy density power systems, and fine pointing control. Missile defense and hyperspectral imaging systems rely on long lifetime cryogenic cooling and focal plane technologies now in development. Miniaturization, increased reliability, and spacecraft autonomy will enable the development of microsatellite vehicles with significant capability. Vehicles weighing less than 100 pounds will conduct missions such as diagnostic inspection of malfunctioning satellites through autonomous guidance, rendezvous, and even docking techniques. Distributed formations of satellites will be electronically linked, providing enhanced capabilities for ISR and information dominance. All of these new capabilities will be managed by new satellite control systems, which reduce the requirements for large, manpower-intensive, expensive ground stations and which provide new capabilities for direct interaction with in-theater commanders.

b. *Overview*

The DoD S&T technology efforts included in the space vehicles subarea encompass the structures, thermal management, command and control, survivability and vulnerability, and space power subareas listed in the Space Technology Inventory under space vehicles plus the subareas of debris and contamination listed under Space Environment.

(1) Goals and Timeframes. The subarea goals, system payoffs, and timeframes for the space vehicles technologies are listed in Table VIII–5. The technologies and associated objectives required to achieve the space vehicles goals and payoffs are detailed in Table VIII–6.

Table VIII–5. Space Vehicles Subarea Goals and Payoffs

Space Vehicles	Baseline—FY96	FY00	FY05
Subarea Goals			
Payload Mass Fraction (kg/kg)	0.30	+50%	+90%
OTV Mass Fraction (kg/kg)	0.16	-40%	-55%
EPS Acquisition Cost ($/W)	Baseline	-5%	-15%
Structure Acquisition Cost ($/kg)	Baseline	-5%	-15%
OTV Acquisition Cost ($/kg)	$2,030	-10%	-40%
System Payoffs			
Launch Mass	Baseline	-35%	-49%
Acquisition Cost	Baseline	-5%	-15%

Table VIII–6. Space Vehicles Subarea Technology Objectives

Year	Technology	Technology Objectives[a]
2000	Space Structures	Reduce Satellite Structure Cost by 10% Reduce Satellite Structural Mass by 35% Decrease Satellite Launch Loads by 80% Decrease On-Orbit Disturbances by 90% Reduce OTV Structure Cost by 35% Reduce OTV Structural Mass by 40%
	Thermal Management	Increase Heat Flux by 60% Increase Heat Transport by 2X Increase Cryogenic Conductance by 75% Increase Thermal Storage Density by 10% Decrease Heater Power by 10%
	Cryogenic Technologies	Increase Life Expectancy by 2.5X Reduce 10K Specific Power by 70% Reduce 10K Specific Mass by 85% Reduce 35K Specific Power by 65% Reduce 35K Specific Mass by 60% Reduce 60K Specific Power by 20% Reduce 60K Specific Mass by 40% Reduce 100K Specific Power by 45% Reduce 100K Specific Mass by 75%
	Survivability & Vulnerability	Reduce TW/AR mass by 75% Reduce TW/AR power by 67% Increase laser threat protection by 2X
	Space Power	Increase Energy Storage Specific Energy by 3X Increase Solar Array Specific Power by 10% Increase End-of-Life Power Conversion Efficiency by 15% Increase Battery Life at LEO by 12%
2005	Space Structures	Reduce Satellite Structure Cost by 25% Reduce Satellite Structural Mass by 50% Decrease Satellite Launch Loads by 85% Decrease On-Orbit Disturbances by 98% Reduce OTV Structure Cost by 55% Reduce OTV Structural Mass by 50%
	Thermal Management	Increase Heat Flux by 3X Increase Heat Transport by 6X Increase Cryogenic Conductance by 3X Increase Thermal Storage Density by 50% Decrease Heater Power by 25%
	Cryogenic Technologies	Increase Life Expectancy by 3.5X Reduce 10K Specific Power by 90% Reduce 10K Specific Mass by 95% Reduce 35K Specific Power by 80% Reduce 35K Specific Mass by 70% Reduce 60K Specific Power by 30% Reduce 60K Specific Mass by 50% Reduce 100K Specific Power by 55% Reduce 100K Specific Mass by 85%
	Survivability & Vulnerability	Reduce TW/AR Mass by 90% Reduce TW/AR Power by 80% Increase Laser Threat Protection by 5X
	Space Power	Increase Energy Storage Specific Energy by 3X Increase Solar Array Specific Power by 60% Increase End-of-Life Power Conversion Efficiency by 65% Increase Battery Life at LEO by 25%

[a]Using 1996 technology levels as baseline.

(2) Major Technical Challenges. The technical challenges in developing advanced technologies and subsystems for space vehicles focus on reducing weight, size, and cost; isolating vibration; and increasing power efficiency, reliability, and overall spacecraft lifetime.

Structures. Space structures and control technical challenges include developing rapid and less costly manufacturing techniques for large launch vehicle structures; accounting for the combined effects of the space environment; developing high-fidelity simulations; reducing electromagnetic interference effects and increasing the reliability and durability of multifunctional structures; ensuring satellite structural isolation without constraints on rattle space (clearance), weight, power, and volume, as well as interaction between the isolator control system and the launch vehicle control system; developing rapid nonpyrotechnic release mechanism; and integrating neural network technology into structural control systems during operation. Additionally, advanced structures such as lightweight mechanisms and inflatable structures enable compact packaging and deployment to provide larger apertures and solar array areas, while lightweight flexible solar arrays are essential to achieve high performance with minimal weight—all crucial elements of microsatellites. The technical approach is to develop and demonstrate satellite multifunctional structures; lightweight, composite launch vehicle structures; and a launch environment attenuation system.

Large precise optical structures that are extremely lightweight present uniquely difficult challenges. High-resolution imaging requires primary mirror surface accuracies ranging from 0.2-µm rms at mid-infrared wavelengths to as low as 0.02-µm rms for visible light. Optics must be developed that can fold for launch using membrane mirror or other ultra lightweight technologies but still have surface accuracies on the order of 100 µm rms. New types of adaptive optics compensation need to be developed that can then reduce the effective surface error to the required 0.2- to 0.02-µm rms range.

Thermal Management. Controls and materials technology challenges include miniaturized 3D configurations of modern electronics. These are difficult to access for heat removal, yet generate high heat flux. Available substrates do not have high enough thermal conductivity in three orthogonal directions.

For ambient cooling, two-phase capillary pumped loops are currently complex, difficult to start and operate under power and environmental changes, and present test difficulties at Earth gravity. Other ambient cooling challenges include variable emissivity concerns about the ability of the vehicle to withstand the charged-particle and ultraviolet environments of space, scale-up from coupon-level work, and integration on large space structures. Liquid/vapor transition energy storage requires a flexible and high-pressure container; deployable radiators require flexible joints across which heat transport fluid must be carried; and “flexible” diode heat pipes are rather stiff.

Cryogenic cooling challenges include availability of lightweight components for use in cryogenic temperatures; excessive friction and material stresses in miniature-sized, high-frequency cycles; preventing contamination of seals and orifices; lack of effective design and materials for cryogenic regenerators; poorly understood thermodynamic loss mechanism; ineffective vibration isolation control electronics and techniques; a “missing fluid” gap between nitrogen and neon; usable cryogenic fluids have very low surface tension; cryogenic temperature energy storage requires high-pressure containment at room temperature; and parasitic heat leak imposes a direct penalty on cryocooler performance.

Survivability and Vulnerability (includes debris). The challenges are to develop radiation-tolerant space devices and systems, develop techniques to allow space applications of commercial-off-the-shelf (COTS) devices, improve reliable high-precision survivability simulations, develop miniaturized laser and radar threat detectors and optical systems jamming protection, and characterize space debris hazards.

Space Power. Space power system technologies challenges include growth and lattice compatibility of advanced semiconductor materials (GaInAsP, CuInSe2) for multijunction and low-cost, ultra-thin solar cells; feasibility and reliability of solar thermal conversion; accelerated correlation of battery design with temperature, depth of discharge, cycling, and rate; minimizing electrical loss in magnetic bearings; improving the reliability and processing of high-strength and high-cycle life composite materials for flywheel systems; and availability of high-voltage (70–130 Vdc), space-qualified, solid-state components and circuits.

(3) Related Federal and Private Sector Efforts.[7] Outside DoD, the primary government organizations funding space vehicles technology development are NASA, the NRO, and DOE. Historically, the NASA investment matches that of DoD in many of the technologies, while the DOE investment is considerably smaller. Formal coordination with NASA is under the DoD/NASA Aeronautics and Astronautics Coordinating Board.

The NRO makes a significant investment in space vehicles technology. The NRO investment in space vehicles is targeted at reducing the time it takes to acquire new systems and achieving dramatic improvements in performance while, at the same time, reducing the cost and weight of the spacecraft. As such, the NRO invests in virtually all areas of spacecraft technology; however, the primary emphasis is on payloads. Efforts are also being made to leverage the substantial commercial investments in this area, especially in trying to use, or develop, a common spacecraft bus that can be used for a variety of commercial or government payloads.

DoD, NASA, and the NRO have joined in the STA (see page VIII–1). The STA membership includes NASA, the NRO, Army, Navy, Air Force, DARPA, BMDO, DDR&E, and DUSD (Space). The STA provides a forum for space technologies and advanced concepts. The STA has established integrated product teams (IPTs) on the following space technologies: advanced power, hyperspectral imaging, large optics, and advanced power. These are areas of common interest among most of the STA organizations. These IPTs are developing joint roadmaps that will identify milestones, technology shortfalls, and opportunities for leveraging technologies and developing cooperative programs. The STA is currently addressing integrating industry into the STA. Another recent effort is the AFSPC–NASA–NRO Partnership Council. This addresses operational and facility issues of space. The Air Force is participating in the development of technologies for both ballistic missile defense and space technologies closely related to ballistic missile defense. The BMDO Joint Technology Board (JTB) is the primary coordinating group that involves the BMDO, Army, Navy, Air Force, and DARPA. The JTB plans, coordinates,

[7] Written in coordination with the NRO. The NRO Office of Corporate Communications may be contacted at (703) 808–1198.

prioritizes, and prepares program objective memorandum budgeting for technologies needed by both BMDO and Air Force for ballistic missile defense-related space and missile systems.

Additionally, there are focused commercial ventures for space-based systems, such as communication and surveillance systems. The recent appearance of a strong, well-capitalized commercial presence in space allows DoD to leverage advances in these systems. Commercial space manufacturers' private capital, short development cycle, and frequent new starts permit a new arena for rapid maturation of space platform technology. DoD has a cooperative research and development agreement with the commercial sector to provide opportunities for space demonstration of the technology and to share in the cost of development in some areas, such as energy storage. Industry has plans for both highly autonomous spacecraft and architectures for large distributed networks of satellites. Similar advances are occurring in the international arena as well.

c. *S&T Investment Strategy*

(1) Technology Demonstrations. The space vehicles technology demonstration program provides an architecture to assist technologies in the validation and assessment of their performance. The technology demonstration architecture spans from small, component-level assessments to integrated demonstrations that address the use of technology in solving warfighter deficiencies. The overall architecture allows for the validation and assessment of technologies in a simulated ground environment or space environment depending on the needs of the experimenter(s) and the environment required to provide a true assessment and validation of the technologies' capabilities in meeting its performance criteria.

USAF Integrated Space Technology Demonstration Program. The USAF ISTD program will demonstrate medium-risk, high-payoff system concepts and payload(s) through the design, integration, and validation of emerging technologies in real-world environments. The objectives of the ISTD program are to show how emerging technologies can be used to resolve high-priority mission deficiencies, validate technology for use in operational systems, examine new methods to demonstrate technologies, and acquire military capability by leveraging commercial space systems whenever possible. ISTDs will have 36-month launch cycles.

As the first ISTD mission, Warfighter–1 (WF–1) objectives are to evaluate and validate hyperspectral technologies in the orbital environment, demonstrate utility of hyperspectral imagery to the government user community, demonstrate leveraging of commercial space systems to meet DoD needs, and launch in 3Q FY00.

The scope of the WF–1 includes design, fabrication, integration, test, launch, spacecraft operations, and algorithm development as well as supporting or performing on-orbit payload operations, mission planning, anomaly resolution, and data reduction and processing. WF–1 will demonstrate emerging sensor technologies and the ability to perform target detection and terrain classification using these technologies. A large portion of the data collected will focus on target and background signatures to serve as a scientific database for algorithm development and exploitation studies within the WF–1 and other programs.

The system requirements for the WF–1 sensor have a total of 280 spectral bands in the spectral region between 0.5 and 3.0 µm. The sensor will have a 5-km minimum swathwidth and a single hypercube image at least 100 km^2. The sensor will provide hyperspectral data necessary to detect targets (listed in Table VIII–7) against various backgrounds. The WF–1 system will be used to develop a database of terrain classification data for the terrain elements including variations due to seasonal changes, sun/look angles, and atmospheric conditions. Space flight is a cost-effective way to acquire the background data over the wide range of conditions and locations. Space flight also provides the means for denied area access coverage.

Table VIII–7. Warfighter–1 Demonstration Conditions

Test Cases	Test Conditions
Tactical Targets Set	Mobile armor (15-m^2 size) Transportable launchers (30-m^2 size) Ships and surfaced submarines (350-m^2 size) Camouflaged targets (25-m^2 size)
Backgrounds	Desert, temperate zone, snow, forest, grasslands, agricultural, littoral zone
Terrain Elements	Desert, littoral zone, snow, wetlands, disturbed soil and vegetation, snow and ice, temperate zone forest, grassland and agricultural, vegetation and coverage, urban, tropical zone, forest

The first ISTD flight will primarily demonstrate FY00 DTO goals for the Hyperspectral Applications Technology (DTO SE.67); secondary goals will be for Cryogenic Technologies (DTO SP.01), Space Structures and Control (DTO SP.03), High-Density, Radiation-Resistant Microelectronics (DTO SE.37), and Digital Warfighting Communications (DTO IS.23). These programs directly support the AFSPC, including the Space Warfare Center, and military users of tactical space imagery.

The second satellite, Warfighter–2 (WF–2), in the ISTD line is currently undefined. The concept definition study is expected to be completed in the second quarter of FY99. As technologies are received, the program office will review each concept for feasibility. The program office will then forward potential concepts for senior management review and approval. As the field is narrowed, a General Officer Steering Committee (GOSC) composed of the user community will be briefed on the final candidate demonstrations. Given constraints, the GOSC will choose the highest priority technology. Upon selection, the ISTD program office will implement an approved business strategy. WF–2 acquisition is expected to formally begin in second quarter FY00.

USAF MightySat. The USAF MightySat program is a quick-turnaround series of small, satellite-based experiments that test a limited set of high-payoff emerging and exploratory technologies. These elements can be either in situ experimental bus components (batteries, solar cells, etc.) or standalone experiments (imagers, sensors, etc.). The MightySat platform functions as an experimental testbed exploring such objectives as demonstrating concept feasibility, developing a critical knowledge base to exploit new capabilities, identifying system risks under space environmental conditions, and providing flight heritage for critical components scheduled for deployment on future DoD space systems. Table VIII–8 details the key technology demonstrations within the MightySat program.

Table VIII–8. USAF MightySat Technology Demonstrations

Flight Experiment	DTO/JWSTP: Technology Demonstrations	Launch
MightySat–I	SP.03, Space Structures and Control—validate manufacturing process for composite structures, I-beam assembly, low-shock release devices	FY99
	SP.08, Space Power System Technologies—validate solar cell efficiency and space environment degradation	
	SE.37, High-Density, Radiation-Resistant Microelectronics	
MightySat–II.1	SP.02, Thermal Management Technology	FY00
	SP.03, Space Structures and Control—high-performance composite structures, structures thermal and radiation shielding	
	SP.08, Space Power Systems Technologies	
	SP.11, Orbit Transfer Propulsion	
	SE.20, ATR for Reconnaissance and Surveillance	
	SE.44, Power Control and Distribution	
	SE.67, Hyperspectral Applications Technology	
MightySat–II.3	Option on contract; payloads not yet manifested	FY04
MightySat–II.4	Option on contract; payloads not yet manifested	FY04
MightySat–II.5	Option on contract; payloads not yet manifested	FY05

Navy EarthMap Observer Program. The NEMO program will demonstrate the capability to use hyperspectral imagery for characterization of the littoral battlespace. NEMO will utilize innovative hyperspectral imaging, onboard parallel processing, and advanced algorithms for spectral and spatial feature identification. The program will develop an inexpensive, long-term, Earth-imaging spacecraft to characterize the optical environment in the littoral zone. NEMO hyperspectral products for naval applications include bathymetry, water clarity, atmospheric visibility, and sea-bottom types. Additionally, NEMO will characterize the littoral optical environment as it affects the performance of Navy optical systems used for the detection of mines, submarines, and submerged hazards. NEMO will also demonstrate the intelligence-gathering and preparation-of-battlespace capabilities of hyperspectral sensing for supporting the warfighter. The innovative processing to be used on this system is the Optical Real-Time Adaptive Spectral Identification System (ORASIS), which was developed by the Navy. ORASIS allows real-time processing of imaging spectrometer data on a spacecraft. The NEMO satellite will be developed in cooperation with industry. Once the prototype has been developed and proven, the technology will be transitioned to industry.

USAF Integrated Ground Demonstration Program. This program is intended to demonstrate high-risk, high-payoff system- and payload-level concepts via the ground integration of emerging technologies. This is accomplished by characterizing technology interfaces and interactions in a simulated environment. This technology integration capability provides the ability for evaluating advanced payload, system, and mission concepts while the hardware and software are still recoverable for future development as well as allowing for the simulation of hardware or software still in the concept phase to be placed in an integrated systems environment. This program supports DTO SP.05, Large, Precise Structures.

STP Small Experiments and Demonstrations. The DoD Space Test Program, managed by the Space and Missile Test and Evaluation Directorate, supports technology developers in the Army, Navy, Air Force, BMDO, and DOE by providing these experimenters with the spacecraft bus, integration of the experiment payloads, launch services, and 1 year's on-orbit operations.

STP funding is used to support experiments that do not have the funding to provide their own means of access to space. In addition, program management directive guidance for STP calls for one small launch vehicle flight (Pegasus-class with satellite of less than 1,000 pounds) every 2 years and one medium launch vehicle flight (Delta-class with satellite of 6,000 to 10,000 pounds) every 4 years. Experiments are selected through the Space Experiments Review Board, which meets annually to consolidate and prioritize space experiments proposed from all of the services and agencies; experiments are ranked primarily by military relevance.

Although STP-sponsored experiments do not individually have significant funding or visibility, collectively they are the backbone of space vehicle S&T program. Examples that are currently manifested (and the flights they are on) are Compact Environment Anomaly Sensor (TSX–5), Beryllium–7-Induced Radiation Experiment (Cosmos), and Polar Orbiting Geomagnetic Survey II (DMSP S–15).

(2) Technology Development. The space vehicles subarea consists of technology efforts in the areas of structures, thermal management, command and control, survivability and vulnerability, and space power. Technology advances in all of these efforts are required to achieve the overall goals of this subarea.

Structures. The structures efforts develop new ways of making lightweight, low-cost, and precise structures for space and launch vehicles and develop new methods to prevent vibration and structural dynamics from degrading the performance of future DoD systems. Other developments include technology for space vehicles; concepts for lighter weight, lower cost, higher performance solar array, radiator, antenna, and electronic enclosure structures; multifunctional structures; and smart mechanisms for solar arrays and other deployable structures. Work on inflatable structures for antennas or optics is included in this technology effort. Work on nozzles and thrusters for spacecraft is included in the space propulsion subarea (Section C3).

Thermal Management. The thermal management efforts develop, demonstrate, and transition technologies to improve the performance, flexibility, and ground testability of on-orbit assets while reducing the mass and heater power requirements of the satellite thermal management subsystem. The efforts entail four programs: central thermal bus, high and pulsed power, cryogenic integration, and high-density electronics cooling.

Command and Control. The C^2 efforts develop technologies to improve the effectiveness and lower the cost of day-to-day space system operations. The primary thrusts in this area are to reduce the number and skill level of personnel required for satellite control through autonomous satellite navigation; computer tools for diagnostics, pass planning, and training; integration of COTS into ground stations; and technologies for control of multiple satellite constellations.

Survivability and Vulnerability. The survivability efforts include advanced hardening techniques, modeling device response to space radiation, and methods to allow COTS devices to operate properly in the lower radiation dose orbits.

Space Power. The space power efforts cover the development of all required components for satellite power subsystems including power generation and energy storage. Technology development includes investigating alternate photovoltaic material and cell designs and increasing the solar concentration ratio of arrays. For energy storage, programs include demonstrating life, performance, and safety of advanced Li-based batteries. Investigations into flywheels and other nonelectrochemical storage devices have also been started.

(3) Basic Research. The space vehicles technology subarea relies on the results of basic research from Information Systems Technology, Materials/Processes, and Sensors, Electronics, and Battlespace Environment as well as programs from other related federal, university, and commercial efforts.

3. Propulsion

Development of new rocket propulsion technologies to meet government and commercial requirements continues to be the pursuit of the various government laboratories and industry. To better focus the nation's investment in rocket propulsion technology, the Integrated High-Payoff Rocket Propulsion Technology program was started in FY94 using 1993 state-of-the-art technologies as baseline. IHPRPT is a goal-oriented, time-phased program actively and continuously coordinating DoD, NASA, and industry investment through 2010 for space launch (boost and orbit transfer), spacecraft, strategic, and tactical propulsion. Although this chapter is concerned with space applications, a few references to tactical and strategic propulsion technologies are shown for completeness and context as there is synergy between the technology areas.

a. *Warfighter Needs*[8]

Propulsion technologies support three basic functions: (1) improve the efficiency and lower the cost of expendable launch vehicles, (2) enable reusable access to space for multiple missions, and (3) increase the efficiency and lower the cost of upper stages. Stronger commercial spacelift demand will, over the long term, obviate some of the Air Force investment in this area for certain missions like generic access to space. Systems like the SOV and SMV will demand strong Air Force investment given the unique multimission capability they provide and the DoD-unique operating regime demanded for their operation. Technologies like high-energy-density matter, tankage structures, and rocket engine components will benefit both the ELV and the reusable communities.

ELVs have been the mainstay for years, with technology refinements only marginally improving performance. In the intervening years until reliable, reusable spacelift is available, ELVs will continue to dominate the spacelift community. The need for inexpensive sparing and replacement launches for commercial satellite communications (MILSATCOM) efforts is driving the spacelift community, over the long term, to reusable solutions. The SOV, along with ELVs, requires a suite of efficient upper stages for insertion into final operational orbits. High specific impulse with modest thrust is desired to reduce transfer times while maintaining very favorable payload mass fractions. Operational assessment of ion propulsion offers improved specific impulse with very low thrust. Solar thermal propulsion has some of the specific impulse advantages with much larger thrust.

Propulsion technologies provide assured and affordable access to space, enabling use of space-based ISR, MTI, multi- and hyperspectral imaging, and BM/C^2. These space-based capabilities support the Joint Warfighting Capability Objectives of Information Superiority, Precision Force, Combat ID, Joint Theater Missile Defense, Chemical/Biological Warfare Defense and

[8] Written by Air Force Space Command (AFSPC/XPX).

Protection and Counter Weapons of Mass Destruction, Force Projection/Dominant Maneuver, and Joint Readiness and Logistics and Sustainment of Strategic Systems.

b. ***Overview***

The focus of the propulsion technology is to significantly reduce the cost of access to space, increase payload capability, increase on-orbit maneuvering capability, and improve propulsion system reliability. A variety of propulsion system solutions are being pursued to provide significant warfighter payoffs.

Space propulsion consists of space launch (boost and orbit transfer) and spacecraft propulsion (propulsion that typically or is foreseen not to be staged from the spacecraft). Space launch propulsion technologies are being pursued for both liquid- and solid-propulsion systems. Electromagnetic, electrostatic, and solar thermal propulsion technologies are being developed for spacecraft propulsion applications.

Component technologies are being pursued in the areas of propellants, propellant management devices (turbomachinery, manifolds, ducting, solid rocket motor case assemblies), combustion and energy conversion devices (thrust chamber assemblies, nozzles, exit cones), and controls (actuators, controllers, health management, thrust vector actuation and control). Once the component technologies are proven at the appropriate scale and environment, they are integrated into a technology demonstrator. In the demonstrator, hardware and propellant scale-up, integration, and testing are accomplished. Once testing and analysis are complete, a comparison is made to assess the level of goal achievement. In effect, this provides an assessment of the ability of the technology developed to provide capability to the warfighter.

(1) Goals and Timeframes. The IHPRPT goals were generated to develop the technologies necessary to provide the required user capabilities through the year 2010. The time necessary to develop technologies required can be 10 years or more; the IHPRPT program is a 15-year program with three phases ending in FY00, FY05, and FY10, respectively.

The propulsion goals are established by the IHPRPT program. The program is based on achieving the FY00 goals shown in Table VIII–9 for boost and orbit transfer (B/OT) and spacecraft through DTOs SP.10, SP.11, and SP.20. Future DTOs will achieve the FY05 and FY10 goals. Strategic sustainment goals for solid-rocket motors are shown, as these JWSTP goals are directly applicable to space propulsion. IHPRPT also has tactical propulsion goals that are overseen by the Conventional Weapons Subpanel.

The goals of the IHPRPT program translate into payoffs to the warfighter in terms of increased capabilities. Payoffs to launch vehicle systems include performance, cost, and reliability improvements to existing launch systems, expendable launch systems, and new reusable vehicles. The operational increases for B/OT propulsion systems by 2000, 2005, and 2010 include 7%, 12%, and 18% increases, respectively, in payload capability for new expendable boosters (over the 25,000-pound baseline to LEO). An alternative to increasing the payload on a lift vehicle would be to launch payloads on smaller, more capable vehicles to reduce the need for costly heavy-lift vehicles. The resulting launch cost reductions would equate to savings of 12%, 20%, and 27% in cost-per-pound to orbit. These savings are in addition to the savings seen from

Table VIII–9. Propulsion (IHPRPT) Subarea Goals[a]

Year	Technology	Goal
2000	B/OT	-25% Failure Rate, +15% Mass Fraction (Solid), +5-sec Isp,[b] -15% Hardware Costs, -15% Support Costs, +30% Thrust/Wt (Liq), 20 Missions MTBR
	Spacecraft	+20%/200% Total Isp/Wet Mass (Electrostatic/Electromagnetic), +5%/10% Isp (Bipropellant/Solar Thermal), +30% Isp Density (Monopropellant), +15% Mass Fraction (Solar Thermal)
	T	+3% Delivered Energy, +10% Mass Fraction (w/TVC), +2% Mass Fraction (w/o TVC), Maintain Cost/Safety/Survivability
	Missile Propulsion[c]	+4% Isp, +1% Mass Fraction, -25% Hardware Cost
	Aging and Surveillance[c]	Increase "Look Ahead" Window From 5 to 10 Years
	Post-Boost Control System	-25% Hardware Cost, Turndown Ratio 5:1
2005	B/OT	-50% Failure Rate, +25% Mass Fraction (Solid), +21-sec Isp, [b] -25% Hardware Costs, -25% Support Costs, +60% Thrust/Wt (Liq), 40 Missions MTBR
	Spacecraft	+35%/500% Total Isp/Wet Mass (Electrostatic/Electromagnetic), +10%/15% Isp (Bipropellant/Solar Thermal), +50% Isp Density (Monopropellant), +25% Mass Fraction (Solar Thermal)
	T	+7% Delivered Energy, +20% Mass Fraction (w/TVC), +5% Mass Fraction (w/o TVC), Maintain Cost/Safety/Survivability
2010	B/OT	-75% Failure Rate, +35% Mass Fraction (Solid), +26-sec Isp, [b] –35% Hardware Costs, -35% Support Costs, +100% Thrust/Wt (Liq), 100 Missions MTBR
	Spacecraft	+75%/1250% Total Isp/Wet Mass (Electrostatic/Electromagnetic), 20%/20% Isp (Bipropellant/Solar Thermal), +70% Isp Density (Monopropellant), +35% Mass Fraction (Solar Thermal)
	T	+15% Delivered Energy, +30% Mass Fraction (w/TVC), +10% Mass Fraction (w/o TVC), Maintain Cost/Safety/Survivability

[a]All percentage goals are percent change from the baseline.

[b]B/OT Isp goal represents a combination of specific propulsion improvements at the following respective levels:
Cryogenic Engine: 1% (2000), 2% (2005)
Hydrocarbon Engine: 13% (2000),15% (2005)
Solid Motor (Castor 120 Propellant): 2% (2000), 4% (2005)
Hybrid Motor: 11% (2005).

[c]Strategic sustainment goals managed by Propulsion Subpanel.

system design and process changes. For a new reusable launch system, the payload improvements by 2000, 2005, and 2010 approach 69%, 121%, and 170% over the life of the vehicle with cost reductions of 57%, 78%, and 90%, respectively.

Spacecraft goals will result in increased warfighter payoffs through reliable critical information gathering and global communication capabilities at reduced costs. Space vehicles in geosynchronous orbit will be able to extend their on-orbit life up to 45%, increase repositioning capabilities by a factor of 2–5, or increase useful mission payload mass by 10%–30%. This last capability can mean an ability to increase the number or types of transponders, potentially manifest the same payload on less expensive launch vehicles, or increase the survivability of the satellite by allowing for increased shielding material. Communication and reconnaissance payloads will be able to reposition more often and more rapidly to support the warfighter needs in local theaters of operation without significantly sacrificing satellite life. More reliable deployment and on-orbit operation throughout the life of the satellite will provide greater assurance in asset availability. Higher performance compact propulsion systems will also enable the deployment of smaller payloads into higher energy orbits. For medium-lift vehicle class geosynchronous space vehicles launched at a conservative rate of six per year, meeting the IHPRPT goals would result in cost savings of $60 million, $130 million, and $240 million by 2000, 2005, and 2010, respectively.

(2) Major Technical Challenges. The doubling of space propulsion system capability will be achieved through a combination of technology initiatives. To meet the propulsion system goals, investigations to increase the energy of propellants, increase the efficiency of combustion processes, increase the combustion chamber operating pressures, decrease the inert weight of propulsion systems, and improve the efficiency of thrust magnitude/vector control systems will be concurrently developed and consolidated. Specifically, propellant developments involve increasing performance (energy, density) and reducing costs (manufacture, storage, handling, testing) while improving the environmental acceptability.

For all rocket propulsion systems, the IHPRPT program will provide cost reductions in a system while improving payload capability. Achieving this goal will require significant performance improvements. Future propellant requirements include improved reliability, increased safety, greater performance, longer service life, and lower life-cycle costs. Propellant management devices, combustion and energy conversion devices, and control systems require innovative subcomponent and component design methods, manufacturing techniques, and materials for the respective component and application area developments. The major advances required in liquid-propellant combustion devices include an increase in theoretical specific impulse (Isp) by increasing chamber pressure, increases in Isp efficiency as measured by Isp actual/Isp theoretical, reductions in weight, reductions in cost, and increases in reliability (measured by a decrease in part count).

The solid propulsion area consists of primarily the motor case, insulation, propellant, nozzles, and the igniter. In solid propulsion, the major advances required are in increasing Isp efficiency, decreasing component weight and volume, decreasing component cost, and increasing reliability.

The electric propulsion area of satellite propulsion includes the power processing components and the thrust chamber assembly, including the electrode. Major advances are needed in improving the power processing efficiency, the energy conversion efficiency, and combustion chamber life.

(3) Related Federal and Private Sector Efforts.[9] All DoD agencies, NASA, and industry participate in IHPRPT. Industry rocket propulsion independent research and development investment for FY97 is approximately $30 million. NASA FY97 investment for IHPRPT-related programs for the RLV is approximately $10 million. The NRO does not invest in propulsion.

c. *S&T Investment Strategy*

The key to the IHPRPT process is the simultaneous achievement of the goals. Technology demonstrations conducted during each of the three phases will quantify the degree of success in reaching the goals. The technology demonstrators do not have to be a complete propulsion sys-

[9] Written in coordination with the NRO. The NRO Office of Corporate Communications may be contacted at (703) 808–1198.

tem demonstration. They may be individual components or a combination of components. The requirement is to prove justifiable, analytical connectivity that the compilation of the demonstrated technologies would work together as an acceptable propulsion unit. As a metric, the empirical or analytical data will be compared to baselines identified at the initiation of IHPRPT. Following demonstration, the technologies may transition economically to new propulsion systems or to improvements to current propulsion systems.

(1) Technology Demonstrations. Technology demonstrations for IHPRPT are divided into three fundamental propulsion classes. Each class is a separate family of demonstrations.

Boost and Orbit Transfer Propulsion. These demonstrations, when successful, fulfill DTOs SP.10 and SP.11. The demonstrators for this mission application area are divided into (1) propulsion systems that lift payloads from ground level to orbit elevation (boost propulsion), and (2) propulsion systems (orbit transfer) that move payloads from one orbit (such as LEO) to another orbit elevation (GEO). Specific boost demonstrations will occur at the end of each IHPRPT phase. In 2000, the component improvements will feed into an integrated demonstration. In 2005, further component improvements will integrate into a high-performance (4,000-psi chamber pressure) booster class demonstration. Orbit transfer component improvements will feed into a FY00 high-performance (1,200-psi chamber pressure) upper stage/orbit transfer demonstration and a FY05 high-performance (1,500-psi chamber pressure) upper stage/orbit transfer demonstration.

Also in this area is the effort for strategic sustainment. This effort is primarily directed at efforts to maintain system capability without relying on strategic-missile-unique materials to reduce cost. Component and propellant efforts are underway for the boost propulsion, post-boost control propulsion, and aging and surveillance. Solid propulsion space launch propulsion and strategic missile technologies where appropriate are being used for both applications.

Spacecraft Propulsion. The technology demonstrators for this mission application include two areas: chemical propulsion (e.g., solar electric) and nonchemical propulsion (e.g., solar thermal) covering work under DTO SP.20. In all cases, these system demonstrations will be conducted at simulated altitude conditions permitting direct measurement of performance at space conditions. Solar electric demonstrations (pulsed plasma thruster and Hall thruster) by 2000 and 2005 will integrate all developments for satellite station keeping and repositioning. By 2010, advanced solar thermal propulsion systems and advanced solar electric propulsion systems (ion thrusters) for orbit transfer missions will be demonstrated.

(2) Technology Development. Once the goals and payoffs have been established and confirmed as worthwhile, the technology advancements needed to achieve the goals are determined. The propulsion technologies in B/OT and spacecraft are divided into the same four component technology areas. These four areas, which represent the rocket propulsion system technology improvement areas, are propellants, propellant management devices, combustion and energy conversion devices, and control systems. The efforts in the propellant area include solid, liquid, hybrid, gels, and liner development. Propellant management efforts include work in tanks, feed systems, bladders, turbomachinery, thermal protection systems, cases, pressurization systems, and insulations. Combustion and energy conversion efforts include work in injectors, igniters, combustion chambers, nozzles, gas generators, preburners, and all components of electric and solar propulsion systems (except the propellant). Control system work includes actuator, health monitoring, thrust management, ordnance, valve, and thrust vector control system development.

The projects are technology specific as opposed to being system specific, allowing for global propulsion system improvements applicable to all rocket propulsion systems. Goals within each application area address where the R&D specialists will overcome operational deficiencies and meet requirements and needs defined by the propulsion system users. Subsequently, goals are subdivided into the component technology improvements needed to meet the goals. These component improvements are identified and represent component area objectives toward which the technologists will work in laboratory R&D projects.

This goal–objective relationship connects the R&D laboratories to the user community in a way that streamlines the work done by both communities and enables the needs of both groups to be satisfied. The result of the IHPRPT process is the fulfillment of a set of goals that integrates the technologists with the user community and provides maximum payoffs for future space systems.

(3) Basic Research. The Air Force Research Laboratory Propulsion Directorate has several basic research projects supporting development in B/OT transfer and spacecraft propulsion. In B/OT, one combustion development project (supercritical combustion), two propellant development projects (chemically bound excited states and nonequilibrium flow characteristics), and three materials development projects for rocket components (synthesis, carbon materials research, and material mechanics research) exist. In spacecraft propulsion, the plasma diagnostics project supports electric propulsion development.