4. Space Transportation

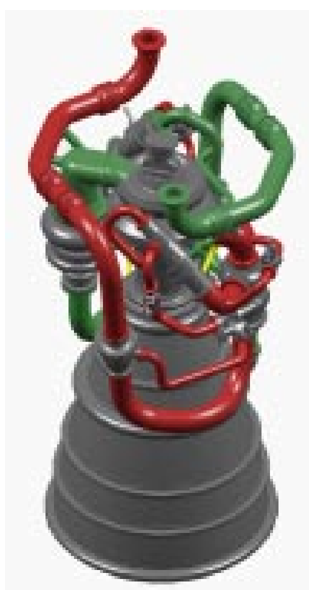
Area Description

Space Transportation encompasses space launch and orbit transfer vehicles and related propulsion systems for the traditional spacelift missions of delivering payloads to orbit and on-orbit spacecraft propulsion for station-keeping, plus emerging missions such as on-orbit refueling, servicing, maintenance, repositioning, and recovery.

The DoD employs both military and commercial expendable launch vehicles, occasionally augmented by use of NASA's Space Shuttle. Military launch systems currently comprise an array of medium- and heavy-lift expendable boosters. The Air Force, NASA and industry are collaboratively funding reusable propulsion technologies with Air Force funding being directed toward supporting militarily unique capabilities. Both independently and in partnership with NASA, industry is developing reusable boosters to add to the launch system inventory and to lower costs to orbit. In addition to military launches, there could be as many as 500 commercial launches worldwide over the next 10 years if costs and risks can be significantly reduced. The DoD is seeking to ease present bottlenecks in access to space via:

- Increased privatization of the launch infrastructure to broaden the launch base
- A launch-on-demand capability, especially for Space Control and other missions where timeliness to orbit or reconstitution of high-demand space-based systems may be paramount.

This area represents the *sine qua non* of space power: unless sufficient lift capability becomes readily available at significantly less cost, U.S. capabilities to place its projected systems on orbit in sufficient quantities to achieve mission objectives will increasingly lag behind demand. Major technological advances leading to improved launch capability will be needed to achieve the very first of USSPACECOM's objectives for the future — Assured Access to Space — without which its other objectives may remain beyond reach.



Propulsion Technology

Improvements to lift capability may be achieved by improving launch and propulsion systems, by reducing the size and weight of spacecraft and payloads, or by some combination of the two. Heavy lift will be needed indefinitely for outsize cargo, so improvements in engines and propellants continue to be a priority. On the other hand, as increasingly fewer spacecraft can do more from a given orbit and/or live longer on orbit, replacements are needed less often, which also reduces relative demand on launch assets. The advent of reusable launch vehicles (RLVs) will reduce per unit launch costs even further. In parallel, we continue to reduce spacecraft size and weight on both a unit and constellation basis. As this miniaturization approach enables entire new classes of small and microsatellites to meet mission utility criteria (see Section 12), the space transportation infrastructure of the future may also include assets that remain on orbit or are recoverable for reuse. Such space support vehicles could provide orbit-changing and maintenance services, thus potentially reducing the life-cycle costs of many space systems.

Several system approaches are summarized in "Projected Applications" below, ranging from current acquisition programs to far-term concepts dependent on near-term technology investment and successful results. In addition, commercial initiatives may also be leveraged for national security space utility (see Appendix I).

When these trends and tradeoffs are additionally augmented by on-orbit servicing and replenishment functions (see Section 5), projected launch assets and on-orbit transfer techniques will achieve new levels of capability, efficiency, and flexibility. As a far-term objective, our national space capabilities would be enhanced immeasurably if space launch, on-orbit maneuvers and even recovery could become as responsive, flexible and reliable as they currently are for manned aircraft.

Mission Area Objectives

- Access to space to be:
  - Routine
  - Assured
  - Low cost
  - Low risk

  with:
  - Launch on schedule (LOS)
  - Launch on demand (LOD)
  - Orbit transfer
  - On-orbit repositioning and servicing

Supporting Capabilities

Reusable into-orbit vehicles (space planes, air launch concepts)

Reusable high-performance rocket engines

Air-breathing/rocket engine combinations

Improved guidance and precision control

Alternative fuels and power sources

Reduced spacecraft weight and cost

Standard modular interfaces

Graceful reentry

Current Technology Initiatives *(Highlights of Current FYDP)*

Space Transportation technology initiatives are spread across several areas: vehicle structures, propulsion, power, materials, thermal protection systems, and flight and ground systems.

The largest investment is in the Integrated High Payoff Rocket Propulsion Technology (IHPRPT) program. IHPRPT is a jointly planned national initiative which coordinates the efforts and investments of the military Service, NASA and industry to demonstrate aggressive propulsion technologies, whose goals include:

- Significantly reduced launch costs
- Increased satellite life and on-orbit capability (repositioning and potentially on-orbit servicing or retrieval)
- Increased tactical missile effectiveness
- Sustainment of strategic systems capability.

Advanced materials and component and propulsion system technologies for solid, liquid, hybrid, solar electric, solar thermal and gel propellant systems are being pursued to provide these capabilities.

The boost and upper-stage development will also address technology needed for the Military Spaceplane (MSP) system. The goal of this area is to increase the performance of rocket engine systems while also increasing their operability and lowering cost.

Space propulsion work includes both propulsion technologies and power storage devices. Electric propulsion technologies like the Hall Thruster and the Pulsed Plasma thruster will enable longer on-orbit satellite life through more efficient uses of fuel. Improved batteries for power storage will increase the power to subsystems while also increasing battery life. The proposed Orbital Express program will develop and demonstrate robotic techniques for on-orbit functions that could support a wide range of future national security and commercial space programs.

For thermal protection systems, more weather-tolerant and robust materials are being developed as well as mechanical attachments for rapid removal and reattachment. Numerous flight and ground systems are addressing rapid turnaround and reductions in the support infrastructure for launch vehicles.

Selected project detail is tabulated in "Projected Applications," below.

Enabling Technologies *(Unconstrained)*

Boost and Orbit Transfer Vehicles and Propulsion:

- Vehicle structures and materials
- Structural controls and dynamics
- Guidance, navigation and control
- Cryogenic liquid oxygen/hydrogen rocket engines (cryoboosters, upper stages)
  - E.g., turbo pumps, combustion chambers, hydrostatic bearings, radiation-cooled nozzles, materials, controls
- Hydrocarbon liquid rocket engines
- Solid rocket motors (SRMs)
  - E.g., composite cases and nozzles, propellants, insulation
- Combined-cycle engines (air-breathing gas turbines and rockets)

Spacecraft Vehicles and Propulsion:

- Multifunctional structures and materials
- Cryogenic cooling
- Guidance, navigation, and control
- Electric propulsion (Hall effect, ion and plasma thrusters)
  - E.g., power-processing electronics, propellant flow controls, magnetics
- Chemical propulsion
- Post-boost control systems
  - E.g., propellants, valve materials, controls
- More efficient solar cells and 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

Generic Propulsion (Boost and Orbit):

- Lightweight, high-temperature materials for rocket engines
  - E.g., ceramics, rapidly densified carbon-carbon, nanophase aluminum
- Solar thermal/chemical propulsion
  - E.g., inflatable/expandable concentrators and structures, combustion chambers, propellant management, materials
- Protective coatings, thin films
- Interoperable (plug-and-play) software, electrical and mechanical interfaces
- Guidance, navigation and control technologies
  - E.g., gyroscopes, accelerometers, inertial measurement units (IMUs), and wind look-ahead for dynamic pressure and bending moment reduction
- Propellants
  - E.g., energetic low-cost, low-hazard and nontoxic chemical propellants (with higher specific impulse and long storage capabilities)
- Structures and shielding
  - High strength-to-weight and composite materials, processes, and manufacturing techniques; e.g., non-autoclave processing materials and methods for large tanks
  - Vibration, acoustic and thermal control and protection
  - Radiation hardening and shielding of components
  - Lightweight, radiation-hardened and/or composite materials, and their design and processing
  - Integrated vehicle health monitoring (IVHM)
- Non-destructive evaluation (NDE)

Reentry:

- Advanced temperature/erosion/vibration-tolerant materials and technologies to assure reentry for reusable spacecraft:
  - Advanced materials for SRMs and reentry vehicle leading edges
  - Plasma effects technology to minimize signal blackout
  - Improved window/antenna materials for reentry systems.

Projected Applications

Applications evolve from expendable to largely reusable boosters during the next generation.

Category	Project	Status	Agency
<u>**LAUNCH ON SCHEDULE**</u> **Low-Cost Launch Vehicles** To provide low-cost, routine and reliable access to space	• ***Evolved Expendable Launch Vehicle (EELV)*** to lower launch costs by ≥25% – Medium- and heavy-lift variants (MLV, HLV) – First MLV launch planned for FY02; first HLV launch planned for FY04	Engineering Development	Air Force
	• ***Integrated High Payoff Rocket Propulsion Technology (IHPRPT)*** Joint DoD/NASA/U.S. industry S&T program for space launch, spacecraft, and strategic and tactical missile propulsion development – Solid Booster Demo in FY01 (EELV and air launch concepts) – Hall Effect Thruster: Life testing complete in FY01 – Solar Thermal Integrated System: Ground test in FY01 – Cryo Upper Stage Expander Cycle Engine Demo in FY02 (EELV, Atlas, Delta, Titan) – Cryoboost (full flow cycle) Engine Demo in FY03 (for EELV and Reusable Launch and Space Operations Vehicles) – Post-Boost Control System Demo in FY03 – Aging Surveillance Demo in FY03 – Phase II Liquid Engine Demo in FY05	Technology Development and Demonstration	Air Force Navy Army NASA Industry
<u>**LAUNCH ON DEMAND**</u> **Military Spaceplane** To combine atmospheric and space transportation technologies	• ***Reusable Launch Vehicle (RLV)*** – Next-generation Space Shuttle – Flight-testing of X-33 subscale prototype to follow FY00 ground tests; tests for X-37 to follow thereafter – Goal: To lower payload-to-space cost by up to 10x (to as little as $1000/lb)	Demonstration (2nd-Generation Development)	NASA
DoD will leverage RLV technologies for its own space lift and transportation concepts	• ***Space Operations Vehicle (SOV)*** – Continental U.S. (CONUS) -based reusable light/medium-lift space transportation vehicle (technologies from NASA's X-33 RLV prototype)	System Concept	Air Force
	• ***Space Maneuver Vehicle (SMV)*** – Reusable spacecraft deployed from the SOV to deliver satellite payloads, perform on-orbit reconnaissance and other functions for up to a year, and return to Earth for service and reuse (X-37; X-40) – X-40B projected as a militarized X-37 (to be used as an operational demonstrator)	System Concept	Air Force
Air Launch Concept	• ***Air Launch Vehicle*** – Reusable aircraft coupled with solid rocket launch system	System Concept	Air Force

<table>
<tr><th>Category</th><th>Project</th><th>Status</th><th>Agency</th></tr>
<tr><td rowspan="2"><u>ORBIT TRANSFER</u>
Spacecraft/Orbit Transfer Vehicle
To use advanced propulsion concepts to reposition spacecraft, once on orbit</td><td>• Advanced propulsion concepts, such as:
– Electric (ion/Hall/pulsed plasma thrusters)
– Solar thermal</td><td>Technology Concepts</td><td>Air Force</td></tr>
<tr><td rowspan="2">• Orbital Express (OE)
– Combine new technologies, operational concepts and modular spacecraft design at significantly reduced life-cycle costs (LCC)
– OE's Autonomous Space Transporter and Robotic Orbiter (ASTRO), its micro-shuttle, will demonstrate capability to host and provide bus services to microsatellites, and would enable the design of new-generation satellites capable of on-orbit refueling and electronics upgrade, thus further reducing launch costs while providing life-extending configuration and operational benefits
– OE's next-generation satellite (NextSat), a modular and reconfigurable spacecraft and payload with standardized modules and interfaces, will demonstrate serviceable satellite feasibility, mission utility from on-orbit avionics upgrades, increased design flexibility, and lower costs
– OE would also develop technologies for "space delivery vans" to provide orbit-changing services to a variety of spacecraft</td><td rowspan="2">Technology Concept
(ATD Proposal)</td><td rowspan="2">DARPA</td></tr>
<tr><td><u>ON-ORBIT SERVICING</u>
On-Orbit Servicing Vehicle
For spacecraft diagnostics and repair, and replenishment of its consumables while on orbit</td></tr>
</table>

Opportunities for Partnering

Under the national DoD/NASA/U.S. industry IHPRPT program, the Air Force is teamed with NASA, the Army, the Navy and the major U.S. propulsion contractors in joint, goal-oriented planning and development of new technologies. These investments provide the foundation for new space propulsion capabilities and resolution of current propulsion-related problems. The eight major IHPRPT demonstration programs are listed chronologically in the preceding table, and described more fully in Appendix G.

NASA's investment in its Integrated Space Transportation Plan (ISTP) program could provide the DoD with many of the technologies required for the SOV and SMV programs. Industry partnerships will be needed to focus and develop technologies for the Air Force's Spacecraft/Orbit Transfer Vehicle (SOTV) program. Close coordination between DoD and NASA will provide smooth technology transition. DoD's focus will be to share costs with NASA on programs applicable to military systems, with particular emphasis on system operability. The Air Force will leverage the DoD and NASA Dual Use S&T programs to help fund the SOTV and associated technologies in association with industry. NASA has expressed an interest both in flight-testing a larger-scale X-43 with the HyTech-developed scramjet engine and using it in a series of flight demonstrations of a wide variety of potential engine configurations.

The DoD Space Test Program (STP) conducts space missions to provide risk-reducing demonstrations of advanced technologies in operational space environments for DoD agencies that do not have routine access to space. With the Air Force as executive agent, the STP supports spaceflight for the military Services and many other U.S. Government agencies (see Appendix G).