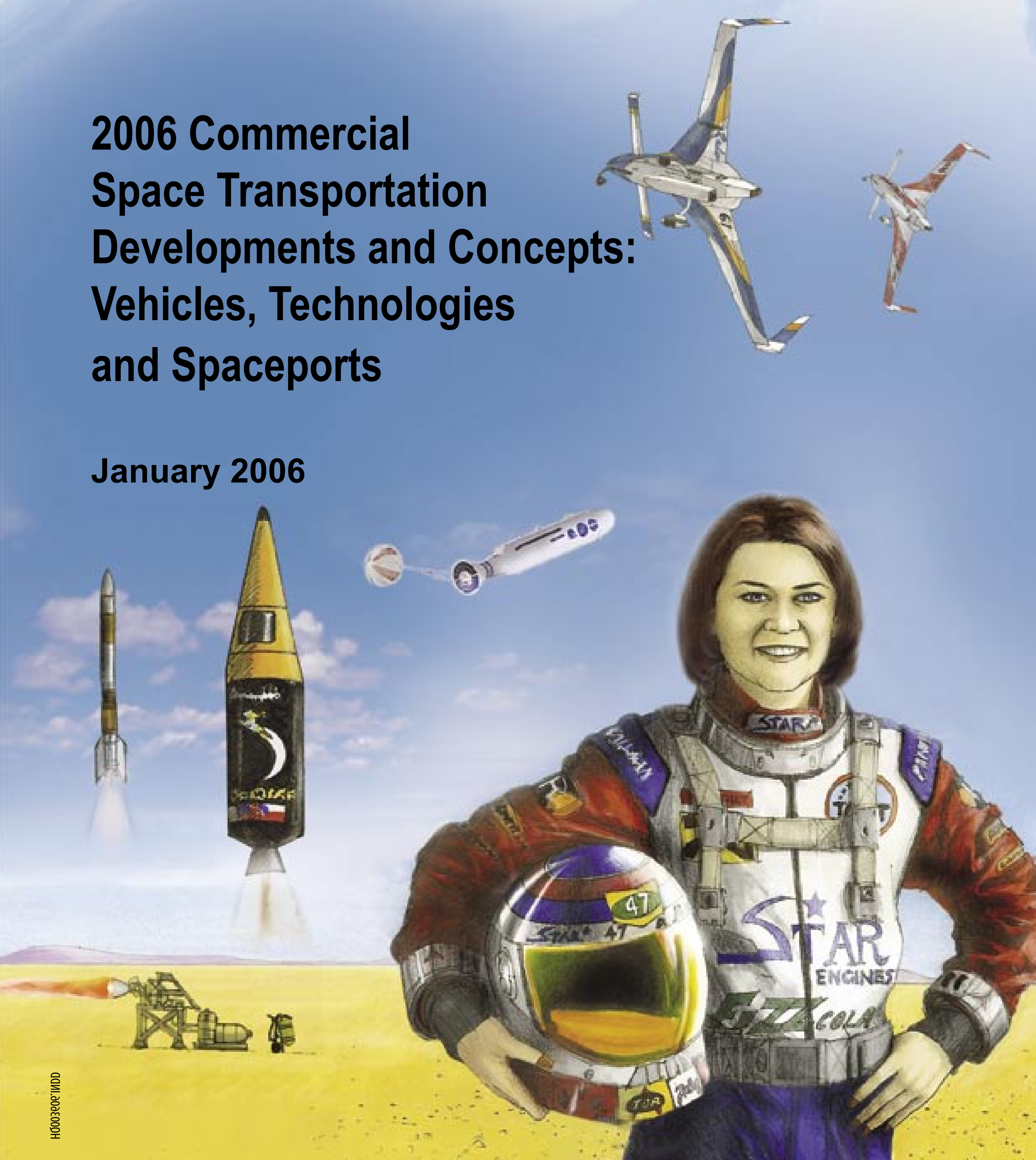
FAA
Commercial Space
Transportation

# 2006 Commercial Space Transportation Developments and Concepts: Vehicles, Technologies and Spaceports

## January 2006



# About the Office of Commercial Space Transportation

The Federal Aviation Administration's Office of Commercial Space Transportation (FAA/AST) licenses and regulates U.S. commercial space launch and reentry activity, as well as the operation of non-federal launch and reentry sites, as authorized by Executive Order 12465 and Title 49 United States Code, Subtitle IX, Chapter 701 (formerly the *Commercial Space Launch Act*). FAA/AST's mission is to ensure public health and safety and the safety of property while protecting the national security and foreign policy interests of the United States during commercial launch and reentry operations. In addition, FAA/AST is directed to encourage, facilitate, and promote commercial space launches and reentries. Additional information concerning commercial space transportation can be found on FAA/AST's web site at http://ast.faa.gov.

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# List of Acronyms

AADC – Alaska Aerospace Development Corporation

ACES – Air Collection and Enrichment System

AFB – Air Force Base

AFFTC – Air Force Flight Test Center

AFRL – Air Force Research Laboratory

APO – Announcement of Partnership Opportunities

ARES – Affordable Responsive Spacelift

ASAT – Amateur Spaceflight Association

AST – Office of Commercial Space Transportation

ATV – Automated Transfer Vehicle

BLS – Boeing Launch Services

C/NOFS – Communication/Navigation Outage Forecasting System

CAIB – Columbia Accident Investigation Board

CALVEIN – California Launch Vehicle Initiative

CCAFS – Cape Canaveral Air Force Station

CEV – Crew Exploration Vehicle

CONUS – Continental United States

COTS – Commercial Off-The-Shelf

CRV – Crew Rescue Vehicle

CSIA – Clinton-Sherman Industrial Airpark

CSULB – California State University, Long Beach

CTV – Crew Transfer Vehicle

CXV – Crew Transfer Vehicle (t/Space)

DARPA – Defense Advanced Research Projects Agency

DART – Demonstration of Autonomous Rendezvous Technology

DoD – U.S. Department of Defense

EAFB – Edwards Air Force Base

EELV – Evolved Expendable Launch Vehicle

ELTR – Eastern Launch and Test Range

EIS – Environmental Impact Statement

ELV – Expendable Launch Vehicle

ERV – Expendable Rocket Vehicle

ESR&T – Exploration Systems Research and Technology

FAA – Federal Aviation Administration

FALCON – Force Application and Launch from CONUS

FDOT – Florida Department of Transportation

FIRST – Future Interagency Range and Spaceport Technology

FSA – Florida Space Authority

FTP – Florida Transportation Plan

GCRSDC – Gulf Coast Regional Spaceport Development Corporation

GEM – Graphite Epoxy Motor

GEO – Geosynchronous Earth Orbit

GPS/INS – Global Positioning System/Inertial Navigation System

GSC – Garvey Spacecraft Corporation

GTO – Geosynchronous Transfer Orbit

HTHL – Horizontal Takeoff, Horizontal Landing

HTPB – Hydroxyl Terminated Polybutadiene

HX – Hydrocarbon X

HYSR – Hybrid Sounding Rocket

ICBM – Intercontinental Ballistic Missile

ILS – International Launch Services

IOS – Interorbital Systems

IPD – Integrated Powerhead Demonstrator

IPF – Integrated Processing Facility

ISS – International Space Station

ISTP – Integrated Space Transportation Plan

ITAR – International Traffic in Arms Regulations

JSC – Johnson Space Center

KLC – Kodiak Launch Complex

KSC – Kennedy Space Center

LAP – Launch Assist Platform

LC – Launch Complex

LEO – Low Earth Orbit

LFF – Liquid Fueling Facility

LNG – Liquid Natural Gas

LOX – Liquid Oxygen

MARS – Mid-Atlantic Regional Spaceport

MAV – Mojave Aerospace Ventures

MDA – Missile Defense Agency

MEMS – Microelectromechanical Systems

MEO – Medium Earth Orbit

MIPCC – Mass Injected Pre-Compressor Cooling

MPV – MIPCC-Powered Vehicle

MSFC – Marshall Space Flight Center

MSLV – Microsatellite Launch Vehicle

MTA – Mojave Test Area

NASA – National Aeronautics and Space Administration

NAWC – Naval Air Warfare Center

NCSS – National Coalition of Spaceport States

NGLT – Next Generation Launch Technology

NLV – Nanosat Launch Vehicle

NRO – National Reconnaissance Office

NTPS – National Test Pilot School

ORS – Operationally Responsive Spacelift

OSIDA – Oklahoma Space Industry Development Authority

OSP – Orbital Space Plane

PDR – Preliminary Design Review

QRLV – Quick Reaction Launch Vehicle

R&D – Research and Development

RASCAL – Responsive Access, Small Cargo, Affordable Launch

RCS – Reaction Control Systems

RFI – Request for Information

RLV – Reusable Launch Vehicle

RP-1 – Rocket Propellant 1

RSTS – Range Safety and Telemetry System

RTS – Reagan Test Site

SBIR – Small Business Innovation Research

SLC – Space Launch Complex

SLEP – Service Life Extension Program

SLI – Space Launch Initiative

SLV – Small Launch Vehicle

SRS – Southwest Regional Spaceport

SSI – Spaceport Systems International, L.P.

SSME – Space Shuttle Main Engine

SSO – Sun-synchronous Orbit

STS – Space Transportation System

TCP/IP – Transmission Control Protocol/Internet Protocol

TSTO – Two-Stage-To-Orbit

UAV – Unmanned Aerial Vehicle

USAF – U.S. Air Force

VAFB – Vandenberg Air Force Base

VCSFA – Virginia Commercial Space Flight Authority

WAA – Wisconsin Aerospace Authority

WFF – Wallops Flight Facility

WFNA – White Fuming Nitric Acid

WSMR – White Sands Missile Range

# Introduction

In 2005, the commercial space industry built on the giant leaps forward of the previous year, making steady progress toward promising launch vehicles, improved technologies, and responsive spacelift capabilities that will serve both commercial and government needs. No new vehicles entered service, but rapid development continued and it appeared certain that the Falcon 1, built by Space Exploration Technologies Corporation (SpaceX), would soon make its launch debut. Meanwhile, the United States Department of Defense (DoD), through a host of initiatives, continued to fund development of new vehicle families that will be able to launch quickly and cheaply, and be versatile enough to satisfy military and commercial customers. Finally, prospects for suborbital space tourism appeared stronger than ever as companies invested in vehicles and spaceports, gained regulatory approval, explored business models, and laid the groundwork to commence commercial operation before the end of the decade.

This report explores these themes, as well as the major events that defined U.S. commercial space transportation in 2005. It showcases current and planned U.S. commercial or commercially-oriented activities. In 1998, when the Federal Aviation Administration Office of Commercial Space Transportation (FAA/AST) first published U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports, the report only focused on reusable launch vehicles (RLVs). The commercial launch landscape has changed significantly since then, and accordingly, this report addresses space competitions, expendable launch vehicles (ELVs), enabling technologies such as propulsion and launch configurations, and the evolving array of U.S. spaceports.

Whether new developments are highly publicized occurrences or gradual changes, commercial space transportation remains a dynamic industry. Providing a well-rounded understanding of today's commercial launch sector requires examining a broad range of topics. Information presented in this report was compiled from open sources and through direct communication with academic, federal, civil, and corporate organizations. Because many of the statements herein are forward-looking, the most current information should be obtained by contacting the organizations mentioned in this report directly.

## Space Competitions

Excitement over the 2004 success of Scaled Composites' SpaceShipOne in winning the Ansari X Prize persisted in 2005, even though no manned suborbital launches immediately followed. However, the X Prize Foundation continued to encourage innovation in what it has termed the emerging "personal spaceflight industry" through a new contest known as the X Prize Cup. The X Prize Cup will be an annual event in New Mexico, slated to officially kickoff in the near future. It will provide cash prizes to vehicle developers who achieve milestones such as fastest launch turnaround time, maximum altitude, and fastest speed record. The purpose is to provide a tangible financial incentive for technological competition and inspire public interest in commercial spaceflight. To that end, in October 2005 the X Prize Foundation held an expo in New Mexico, "The Countdown to the X Prize Cup," featuring vehicle prototypes and technology demonstrators.

Robert Bigelow of Bigelow Aerospace has also proposed a commercial space competition: America's Space Prize. The $50-million prize, valid through January 10, 2010, challenges U.S. entrants to produce a privately funded, reusable vehicle capable of carrying at least five people into two consecutive 400-kilometer (240-mile) orbits, and repeating the feat within 60 days. No such vehicle has yet emerged.

In 2004, NASA also entered the space competition arena with its Centennial Challenges program, which reflects NASA's goal of returning to the Moon by 2020. The challenges will award cash prizes for technologies contributing to an orbital crew transport vehicle, cryogenic storage and transfer devices for in-space propellant provisioning, and the launch of a small lunar lander that could carry a certain amount of weight to the Moon at a fraction of the current cost.

## Expendable Launch Vehicle Industry

2005 saw a decline in U.S. commercial launch activity compared to 2004. In 2004, FAA/AST licensed nine orbital launches and five suborbital SpaceShipOne launches. In 2005, it licensed only five commercial orbital launches-four Zenit 3SLs, marketed by Sea Launch through Boeing Launch Services (BLS), and one Atlas 5, built by Lockheed Martin and marketed by International Launch Services (ILS). Additionally, two ELVs-Lockheed Martin's Atlas 3 and Titan 4-were retired from service in 2005.

Despite these numbers, several companies continued to develop new ELV concepts in 2005, including Space System Loral's Aquarius, E'Prime Aerospace's Eaglet, Lockheed Martin's FALCON SLV, Garvey Spacecraft Corporation's Nanosat Launch Vehicle, Microcosm's Eagle, AirLaunch LLC's QuickReach, and Sea Launch's upgraded Zenit 3SLB "Land Launch" vehicle. Most of these designs focus on the small payload market, so the success of these vehicles may rely on the ability to reduce launch costs enough to enable new markets.

## Reusable Launch Vehicle Industry

At year's end, the RLV concept closest to fruition—SpaceX's partially reusable Falcon 1 vehicle—appeared poised for its maiden launch. The outcome of this launch may affect the business and design plans of other proposed orbital RLVs, including Interorbital System's Sea Star and Neptune, TGV Rocket's Michelle-B, and XCOR Aerospace's Xerus.

Parallel to private RLV development efforts, DoD initiatives such as Operationally Responsive Spacelift (ORS) have resulted in the Defense Advanced Research Program Agency (DARPA) Force Application and Launch from Continental United States (FALCON) program, as well as the Affordable Responsive Spacelift (ARES) vehicle. The ARES vehicle would feature a reusable fly-back lower stage to minimize launch costs. The Air Force expects to develop a prototype by 2010.

2005 saw sustained interest in suborbital RLVs, as the U.S. State Department paved the regulatory way for Britain's Virgin Galactic to join the U.S. firm Scaled Composites in forming The Spaceship Company, which will develop SpaceShipTwo, the commercial version of SpaceShipOne. Other would-be suborbital RLVs, including AERA's Altairis, Armadillo Aerospace's Black Armadillo, Blue Origin's New Shepard, and Rocketplane's Rocketplane XP remain under development.

## Enabling Technologies

NASA and DoD needs remained the primary driver of enabling technology development in 2005. NASA's need for ISS resupply solutions absent the Space Shuttle, as well as new capabilities for the proposed Moon and Mars missions, facilitated development of the Crew Exploration Vehicle (CEV). In June, NASA narrowed the number of potential CEV developers from eight teams to two—Lockheed Martin and a Northrop Grumman-Boeing collaboration. Meanwhile, NASA sought crewed, reentry, automated transfer, and ISS maintenance vehicle design concepts from t/Space, SPACEHAB, and Lockheed Martin, among others.

The DoD's ORS and DARPA FALCON initiatives continued to inspire efforts among engineering firms and vehicle manufacturers to develop more powerful propulsion systems, more efficient engines, and more advanced cryogenic fuel tanks.

## Spaceports

In 2005, existing federal and non-federal spaceports sought to expand their capabilities to entice an emerging commercial responsive and suborbital space tourism market. Most notably, California's Mojave Airport (an FAA-licensed spaceport) received $7.5 million from the FAA to extend its runway to accommodate horizontal RLV landings, and the Florida Space Authority (FSA) took the first steps toward establishing a commercial responsive spaceport in Florida.

Of several proposed spaceports, sites in Texas and New Mexico made the most progress. In January, Blue Origin, a space tourism company run by Amazon.com founder Jeff Bezos, announced plans to construct a test range for its proposed New Shepard launch vehicle near Van Horn in West Texas. In December, Virgin Galactic reached a 20-year lease agreement for use of a New Mexico spaceport scheduled to begin service in 2008 or 2009.

Finally, all spaceport planning occurred against the backdrop of NASA, the DoD, and the FAA's Future Interagency Range and Spaceport Technology (FIRST) initiative. The FIRST initiative seeks to transform U.S. space transportation by making spaceports more like airports: similarly designed, operationally flexible, safe, low-cost, and able to accommodate routine takeoffs and landings.

# Significant 2005 Events

**January 13:** Blue Origin, the commercial space transportation company founded by Jeff Bezos, unveils plans to establish a rocket test range near Van Horn in West Texas for its planned three-person suborbital space tourism vehicle.

**February 3:** Lockheed Martin's final Atlas 3 rocket launches the classified NOSS F3 payload for the U.S. Air Force (USAF) from Cape Canaveral Air Force Station (CCAFS), Florida.

**February 8:** The X Prize Foundation announces that eleven suborbital vehicle developers have agreed to form an industry federation, known as the Voluntary Personal Spaceflight Industry Consensus Organization, to establish safety standards and promote space tourism.

**February 11:** FAA/AST unveils "Draft Guidelines for Commercial Suborbital Reusable Launch Vehicle Operations with Space Flight Participants" and "Guidelines for Commercial Suborbital Reusable Launch Vehicle Operations with Flight Crew." These guidelines include measures designed to ensure safety and security while enabling further space commercialization.

**February 28:** A Sea Launch Zenit 3SL rocket launches the XM 3 communications satellite from Odyssey platform, Pacific Ocean (154° West, 0° North).

**March 4:** The USAF lifts the 20-month contracting suspension it placed on Boeing in 2003 for ethics violations against Lockheed Martin in the contract bid process.

**March 11:** Lockheed Martin's Atlas 5 rocket launches the Inmarsat-4 F1 communications satellite from CCAFS.

**April 26:** A Sea Launch Zenit 3SL rocket launches the Spaceway 1 communications satellite from Odyssey platform, Pacific Ocean.

**May 2:** The USAF awards Space Exploration Technologies Corp. (SpaceX) a $100 million indefinite delivery/indefinite quantity contract to provide responsive small spacelift services through 2010.

**May 9:** The USAF awards Orbital Sciences Corporation a contract to develop the Raptor 1 and Raptor 2 rapid responsive spacelift vehicles. The Raptor 1 will be a winged three-stage air-launched rocket.

**May 11:** The AERA Corporation announces plans to begin commercial service on its Altairis suborbital space tourism vehicle from CCAFS in 2007.

**June 13:** NASA narrows the field of potential Crew Exploration Vehicle (CEV) manufacturers from eight to two, awarding $28 million contracts to Lockheed Martin and a Northrop Grumman-Boeing team to complete final design and development of a CEV prototype. Selection of a single industry team is expected in 2006.

**June 21:** NASA Administrator Mike Griffin formally advocates commercializing International Space Station (ISS) supply efforts, and announces NASA will spend $500 million to develop a requirements-driven vehicle procurement process.

**June 23:** A Sea Launch Zenit 3SL rocket launches the Intelsat Americas 8 communications satellite from Odyssey platform, Pacific Ocean.

**July 26:** Shuttle Discovery returns to flight as the STS 114 mission successfully lifts off from Kennedy Space Center in the first NASA human spaceflight since the February 1, 2003 Columbia accident. Despite fears that thermal insulation tiles were damaged during the launch, the Shuttle lands without incident on August 9.

**August 10:** Space Adventures, the private company that has sent three tourists to the ISS, unveils plans to develop a commercial space tourism service to loop around the Moon by 2010.

**August 15:** The U.S. Department of State Directorate of Trade Controls approves the exchange of technical information between the American company Scaled Composites and Britain's Virgin Galactic, formally clearing the way for their space tourism joint-enterprise, The Spaceship Company.

**September 8:** SpaceX announces plans to develop a third Falcon vehicle, Falcon 9, in addition to its Falcon 1 and Falcon 5 variants. Falcon 9 will be a heavy-lift booster competing with the Atlas 5 and Delta 4 Evolved Expendable Launch Vehicles (EELVs).

**September 19:** NASA Administrator Mike Griffin announces a $104-billion plan to return up to four U.S. astronauts to the Moon by 2018. The plan calls for the CEV to be fully operational no later than 2014.

**October 1:** The Soyuz ISS 11S mission lifts off from Baikonur carrying the third space tourist, Gregory Olsen, who paid $20 million for the orbital flight. Soyuz ISS 11S successfully returns to Earth on October 11.

**October 4:** The X Prize Foundation kicks off "The Countdown to the X Prize Cup" in Las Cruces, New Mexico, an expo showcasing private space vehicle developments and technologies. The Expo was a prelude to the future introduction of the X Prize Cup, a competition aimed at giving the private "personal spaceflight industry" incentives to achieve new technical milestones.

**October 19:** Lockheed Martin's final Titan 4 rocket launches a classified National Reconnaissance Office (NRO) payload from Vandenberg Air Force Base (VAFB), California.

**November 2:** AirLaunch LLC announces it has been awarded a one-year, $17.8 million contract to further develop its QuickReach launch vehicle concept under Phase 2B of the Defense Advanced Research Projects Agency (DARPA) Force Application and Launch from CONtinental United States. (FALCON) program.

**November 8:** A Sea Launch Zenit 3SL rocket launches the Inmarsat-4 F2 communications satellite from Odyssey platform, Pacific Ocean.

**December 6:** NASA solicits proposals for commercial ISS cargo resupply after 2010, when the Shuttle is due to retire. Several companies are expected to submit proposals, including AirLaunch LLC, Andrews Space, Bigelow Aerospace, Constellation Services International, Rocketplane, SpaceDev, SPACEHAB, SpaceX, and Universal Space Lines. Contracts are expected to be awarded in May 2006.

**December 13:** Virgin Galactic reaches a 20-year lease agreement to use a new spaceport planned in New Mexico for the first flights of its suborbital space tourism service, scheduled for 2008 or 2009. The $225 million spaceport will mostly be funded by the New Mexico and federal governments. Virgin Galactic will pay fees of $1 million during each of the first five years of operation, and a larger undisclosed amount after that.

Virgin Galactic also reveals that 38,000 people from 126 countries have paid a deposit on a space tourism flight, including 100 passengers who have already paid the $200,000 price in full.

# Space Competitions

Competitions are recognized mechanisms to drive innovation in commercial industries. The success and popularity of the Ansari X Prize, won in 2004, and other technology competitions have led to the establishment of three major competitions in the space industry to increase the level of innovation in governmental and non-governmental space programs. The end goal of these competitions is to have commercial space launch (and other commercial space capabilities) available for use at lower cost, better quality, and more efficient operations than the options currently available. The competitions currently ongoing are the X Prize Cup, America's Space Prize, and Centennial Challenges.

## X Prize Cup

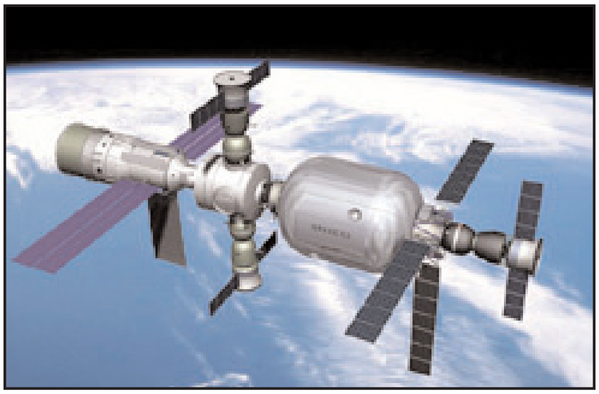
Before the competition for the Ansari X Prize ended, the founders of that challenge decided to establish the X Prize Cup. This new competition will be an annual event in New Mexico, officially beginning in 2006, to advance new concepts and technologies that enable commercial human spaceflight by providing awards and cash prizes. A secondary priority for the competition is to promote education and awareness in the general population about advancements in spaceflight technology. The public will have the opportunity to interact with pioneers in the aerospace industry who are working to reduce the cost and increase the safety and viability of commercial human space travel and view mockups of several planned launch vehicles. For the annual competition, teams will compete in several categories of human spaceflight to win the overall X Prize Cup. These categories include: fastest turnaround time between the first launch and second landing, maximum number of passengers per launch, total number of passengers during the competition, maximum altitude, and fastest flight time. The first competition, a kickoff event called the Countdown to the X Prize Cup, occurred on October 9, 2005 at Las Cruces International Airport, New Mexico. Technology demonstrations that took place during the Personal Spaceflight Expo at the Countdown to the X Prize Cup included:

XCOR EZ-Rocket

- Armadillo Aerospace demonstrated its unmanned vertical-takeoff, vertical-landing vehicle once, with a mishap upon landing that prevented further test flights.
- Starchaser Industries test fired a Churchill MK2 engine, the engine's ninth test fire. The test resulted in an explosion, but caused only minor damage to the engine.
- XCOR Aerospace successfully flew its EZ-Rocket plane (pictured below) twice, piloted by former astronaut Richard Searfoss. The EZ-Rocket is the precursor to the Mark-1 X-Racer that will be used in the newly-announced Rocket Racing League (a competitive racing series that will debut in an exhibition race at the 2006 X Prize Cup and will help mature the rocket technologies that XCOR created).

Other rocket demonstrations—three Tripoli sounding rocket flights—were unable to launch because of poor weather conditions. The Southwest Regional Spaceport (SRS) in New Mexico, which has yet to be constructed, will be the official site for the full X Prize Cup event. Until the SRS is completed, Las Cruces International Airport will be used to host the event, which will take place over two days in October 2006.

## America's Space Prize



Bigelow Aerospace inflatable space modules

Bigelow Aerospace and its founder, Robert Bigelow, have proposed a commercial spaceflight competition: America's Space Prize. This prize challenges entities within the United States to design a reusable vehicle, without government funding, capable of carrying passengers into orbit, with the eventual goal of bringing humans to Bigelow Aerospace's inflatable space modules (pictured above). According to the rules, competitors will have to build a spacecraft capable of taking a crew of no fewer than five people to an altitude of 400 kilometers (240 miles) and complete two orbits of the Earth at that altitude. They must then repeat that accomplishment within 60 days. The first flight does not need to carry any passengers, but the second must carry a full crew. The vehicles will have to demonstrate the ability to dock with Bigelow's inflatable modules and stay docked for at least six months. Bigelow Aerospace plans to have a full-scale module orbiting Earth by 2008 at the earliest, which could be used to demonstrate docking capabilities. The competition deadline is January 10, 2010 with a cash prize of $50 million, funded fully by Bigelow Aerospace.

## Centennial Challenges

NASA has implemented its concept for space technology advancement competitions, bringing important government support to commercial spaceflight development. The Centennial Challenges program creates specialized competitions that will further the exploration of space through specific technological development beyond the usual federal procurement process. NASA held a workshop in June 2004 to gather proposals for competitions to include in the Centennial Challenges. The challenges are organized into four categories as shown in Table 1.

The first of these challenges was announced in March 2005 in partnership with the Spaceward Foundation. These Challenges include tether and beam power technologies with prize money totaling $400,000. Since then three other challenges have been created: the Moon Regolith Oxygen Challenge, the Astronaut Glove Challenge, and the Regolith Excavation Challenge. All of these current challenges are Alliance Challenges that promote future exploration equipment.

For fiscal year 2005, the total budget outlay for the Centennial Challenges program was $20 million. As part of the budget, there was a limit on the amount of prize money to be awarded: NASA was restricted to a $250,000 maximum amount for individual prizes. This prize cap limited the sophistication of the challenges, but the 2005 NASA Authorization Act is likely to authorize greater prize amounts. This potential legislative change will allow for more ambitious competitions to develop advanced technologies.

Table 1: Centennial Challenges Competitions

| Competition Type | Purpose | Prize Value |
|---|---|---|
| Flagship Challenge | Encourage major private space missions | $10-40 million per prize |
| Keystone Challenge | Address technology priorities | $250,000-3 million per prize |
| Alliance Challenge | Leverage partnerships | $100,000-250,000 per prize |
| Quest Challenge | Promote math and science education and careers | Up to $1 million total for Quest program |

While launch vehicles were not a large part of the initial prize competitions, NASA signed a letter of intent with the X Prize Foundation in October 2005 that would create two competitions for launch vehicle technologies, pending the formulation of prize rules and Congressional authorization to award prizes larger than $250,000. Both of these launch vehicle technology competitions intend to have payoffs much greater than the current Centennial Challenges. The first competition, the Suborbital Payload (or X Cup Altitude) Challenge, is to reward development of a reusable suborbital launch vehicle that can carry a payload to sufficient altitudes for conducting space experiments. This challenge is to provide NASA researchers with a vehicle that can fly much higher than was required for the original X Prize. The second competition, the Suborbital Lunar Landing Analog Challenge, will promote development of reusable suborbital vertical takeoff, vertical landing vehicles that can reach certain to-be-determined speeds in order to mimic the technology needed to land and take off from the Moon. Through this competition, NASA hopes to increase the quantity and quality of available engines and landing systems for the agency's return to the Moon.

There are also three potential future Centennial Challenges that could benefit commercial spaceflight technology. These would create competitions for an orbital crew transport vehicle, cryogenic storage and transfer technologies for in-space propellant provisioning, and the launch of a small lunar lander that could carry a certain amount of weight to the Moon at a fraction of the current cost. Current and future Centennial Challenges will increase the technological base in the space industry to benefit NASA and commercial entities, by promoting competition between developers and providing significant monetary rewards.

# Expendable Launch Vehicles

This survey of U.S. ELVs is divided into three sections. The first section reviews the ELVs currently available to serve a wide range of commercial and government payloads. The second section reviews a number of proposed commercial ELVs under study or development that will primarily serve small commercial payloads at prices that are potentially much lower than available today. The final section reviews suborbital sounding rockets manufactured and operated by U.S. companies.

## Current Expendable Launch Vehicle Systems

Table 2 lists the ELV systems available in the United States today. Two ELVs, the Minotaur and Titan 4B, are restricted to government payloads, and Boeing is currently marketing the Delta 4 only to government customers. Once the final Titan 4 vehicle is launched, all large U.S. government payloads will be launched on Atlas 5 or Delta 4 variants. Atlas 5, Delta 2, Pegasus, and Taurus vehicles are available for both commercial and U.S. government launches, and the Zenit 3SL is available only to commercial customers. The two newest members of the U.S. launcher supply, the Atlas 5 and Delta 4 Evolved Expendable Launch Vehicles (EELV), debuted in 2002.

### Atlas 5 - Lockheed Martin Corporation

The Atlas launch vehicle family traces its roots to the development of the Atlas Intercontinental Ballistic Missile (ICBM) in the 1950s. Today, the Atlas family has completed a transition, retiring the older Atlas 2 and 3 in favor of the Atlas 5. The last Atlas 2AS launched in 2004 (giving the Atlas 2AS family the remarkable record of 63 successful launches without a failure). The last Atlas 3 launch took place in 2005.[1]

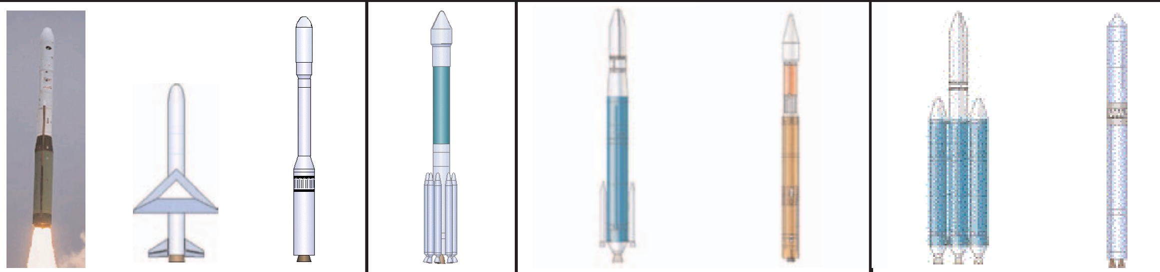
Atlas 5 launch

The maiden flight of the Atlas 5 took place on August 21, 2002, when an Atlas 5 401 vehicle successfully launched the Eutelsat Hot Bird 6 spacecraft from CCAFS. The Atlas 5 is now Lockheed Martin's sole commercial launch vehicle for the foreseeable future. The Atlas 5 family of launch vehicles is based on a common first stage design—known as the Common Core Booster™—and uses the NPO Energomash RD-180 engine introduced on the Atlas 3. The stretched version of the Centaur upper stage, introduced on the Atlas 3B, is also used on single- and dual-engine versions of the Atlas 5.

The Atlas 5 also marks a significant departure in launch preparations compared to previous Atlas versions. The Atlas 5 program uses a "clean pad" concept at Launch Complex (LC) 41 at CCAFS. The launch vehicle is prepared for launch "off pad" vertically in the Vertical Integration Facility near the pad. Hours before a launch, the fully-prepared vehicle is moved to the pad. The Atlas 5 will also launch from LC-3E at VAFB beginning in 2006, and will be standardized to the operating processes at LC-41 except for the use of the more traditional "stack on pad" concept from the heritage launch vehicle programs.[2]

The Atlas 5 is available in the 400 and 500 series and accommodates 4-meter (13.1-foot) and 5-meter (16.4-foot) fairings and up to five strap-on solid rocket motors. The Atlas 400 series can place payloads between 4,950 and 7,640 kilograms (10,910 and 16,843 pounds) into geosynchronous transfer orbit (GTO). The Atlas 500 series can place payloads between 3,970 and 8,670 kilograms (8,750 and 19,120 pounds) into GTO. One commercial Atlas 5 launch took place on March 11, 2005, carrying the Inmarsat 4 F1 satellite, along with one government launch. An estimated two commercial and three government launches are scheduled for 2006.

**Table 2: Currently Available Expendable Launch Vehicles**

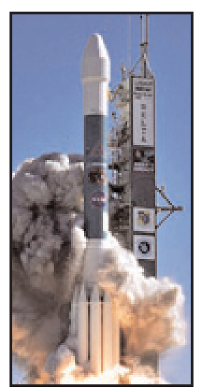
| | Small | | | Medium | Intermediate | | Heavy | |
|---|---|---|---|---|---|---|---|---|
| |  | | | | | | | |
| **Vehicle** | Minotaur | Pegasus XL | Taurus XL | Delta 2 | Delta 4 | Atlas 5* | Delta 4 Heavy | Zenit 3SL |
| **Company** | Orbital Sciences | Orbital Sciences | Orbital Sciences | Boeing | Boeing | Lockheed Martin | Boeing | Sea Launch |
| **First Launch** | 2000 | 1990 | 1994 | 1990 | 2002 | 2002 | 2004 | 1999 |
| **Stages** | 4 | 3 | 4 | 3 | 2 | 2 | 2 | 3 |
| **Payload Performance (LEO)** | 640 kg (1,410 lbs.) | 440 kg (970 lbs.) | 1,360 kg (3,000 lbs.) | 5,100 kg (11,245 lbs.) | 8,870 kg (19,555 lbs.) (Delta 4M) 13,330 kg (29,390 lbs.) (Delta 4M+ (5,4)) | 12,500 kg (27,560 lbs.) (Atlas 5-400) 20,520 kg (45,240 lbs.) (Atlas 5-500) | 23,260 kg (51,280 lbs.) | N/A |
| **Payload Performance (LEO polar)** | 340 kg (750 lbs.) (SSO) | 190 kg (420 lbs.) (SSO) | N/A | 3,895 kg (8,590 lbs.) | 6,870 kg (15,150 lbs.) (Delta 4 M) 10,400 kg (22,930 lbs.) (Delta 4M+ (5,4)) | N/A | 20,800 kg (45,860 lbs.) | N/A |
| **Payload Performance (GTO)** | N/A | N/A | 430 kg (950 lbs.) | 1,870 kg (4,120 lbs.) | 3,930 kg (8,665 lbs.) (Delta 4 M) 6,410 kg (14,130 lbs.) (Delta 4 M+ (5,4)) | 4,950 kg (10,910 lbs.) (Atlas 5-400) 8,670 kg (19,110 lbs.) (Atlas 5-500) | 12,370 kg (27,270 lbs.) | 6,000 kg (13,230 lbs.) |
| **Launch Sites** | VAFB | VAFB, Wallops, CCAFS | VAFB | CCAFS, VAFB | CCAFS, VAFB | CCAFS | CCAFS, VAFB | Pacific Ocean |

* Atlas 5 launches from VAFB are scheduled to begin in 2006.

### Delta 2 - The Boeing Company

The Delta family of launch vehicles traces its heritage to the Thor missile program of the 1950s. Like the Atlas program, the Delta family is undergoing a transition prompted by the introduction of the Delta 4 vehicles developed under the EELV program.

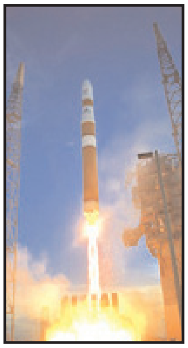
The Delta 2 uses a liquid-oxygen (LOX)/kerosene first stage and a nitrogen tetraoxide and hydrazine second stage. An optional solid-propellant upper stage is available. The Delta 2 also uses between three and nine strap-on solid rocket motors, depending on the performance required. A "heavy" version of the Delta 2 entered service on August 25, 2003, with the launch of NASA's Spitzer Space Telescope spacecraft. This vehicle uses the larger graphite-epoxy motor (GEM) 46 strap-on boosters developed for the now-defunct Delta 3. Although small payload capacity has limited



**Delta 2 launch**

its usefulness for commercial GTO payloads, the Delta 2 is expected to remain in service through 2010, primarily launching military and civil government payloads. Three government Delta 2 launches occurred in 2005; up to seven government launches and one commercial launch are planned for 2006.

### Delta 4 - The Boeing Company



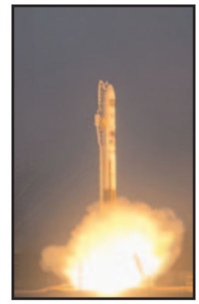
Delta 4 launch

The Delta 4 family of launch vehicles has a common booster core first stage that uses the first new large liquid rocket engine developed in the U.S. since the Space Shuttle Main Engine (SSME) was developed in the 1970s. This engine, the Rocketdyne RS-68, is based on the J-2 engine used on the second stage of the Saturn 5 launch vehicle and technology from the SSME. However, the RS-68 is larger and simpler than the SSME. Depending on customer needs, two or four solid-fuel strap-on boosters, two types of upper stages, and three payload fairings can supplement the RS-68 engine. This vehicle will be launched from VAFB and CCAFS. The first Delta 4 launch took place on November 20, 2002, successfully lofting the Eutelsat W5 spacecraft from CCAFS.

A distinctive design feature of the Delta 4 is its use of horizontal integration. The vehicle is assembled, tested, and prepared for launch horizontally, away from the launch pad. When integration is complete, the vehicle is moved to the pad, raised, and launched in a relatively short period. In addition to making the launch vehicle easier to work on by keeping it closer to the ground, this integration method greatly reduces time spent occupying the launch pad. Boeing expects to reduce pad time from Delta 2's 24 days to a period of about a week for the Delta 4.

Boeing offers five versions of the Delta 4 to address a broad range of payload mass classes. These include four medium versions, each with one common booster core, and one heavy-lift version that uses three parallel common booster core stages. Three of these versions, the Delta 4 Medium-Plus vehicles, were originally optimized for commercial use. The Medium and Heavy versions are largely intended for government use. Payload capacities to low Earth orbit (LEO) range from 8,120 kilograms (17,905 pounds) for the Medium to 23,040 kilograms (50,800 pounds) for the Heavy. GTO capacities range from 4,210 to 13,130 kilograms (9,285 to 28,950 pounds). The Delta 4 has also replaced the Delta 3. While no Delta 4 launches took place in 2005, up to five are planned for 2006.

### Minotaur - Orbital Sciences Corporation



Minotaur launch

The Orbital/Suborbital Program Space Launch Vehicle, also known as Minotaur, was developed by Orbital Sciences Corporation under contract to the USAF to launch small government payloads. The Minotaur 1 booster uses a combination of rocket motors from decommissioned Minuteman 2 ICBMs and upper stages from Orbital's Pegasus launch vehicle. The Minotaur's first two stages are Minuteman 2 M-55A1 and SR-19 motors. The upper two stages are Orion 50 XL and Orion 38 motors from the Pegasus XL. All four stages use solid propellants. Orbital Sciences will also operate the Minotaur 4, which uses stages from former U.S. Peacekeeper missiles. Minotaur 4 can deliver a 1,750-kilogram (3,860-pound) payload to LEO. The Minotaur 4 is expected to enter service no earlier than 2008.[3]

In its January 26, 2000, debut, the Minotaur 1 successfully launched the FalconSat and JAWSAT satellites from VAFB. Two Minotaur 1 launches took place in 2005, the first such launches since 2000; two more are planned for 2006.

### Pegasus - Orbital Sciences Corporation

Pegasus is an air-launched ELV used to place small payloads into a variety of low Earth orbits. Developed by Orbital Sciences Corporation in the late 1980s, Pegasus became the first commercial air-launched system. The Pegasus booster has three solid propellant stages and an optional hydrazine monopropellant upper stage.

The booster is carried aloft under Orbital Sciences' "Stargazer" L-1011 carrier aircraft to an altitude of 11,900 meters (39,000 feet), where it is


Pegasus in flight

released. (Early Pegasus launches used a B-52 aircraft leased from NASA.) The booster drops for five seconds before igniting its first stage motor and beginning ascent to orbit. The original Pegasus booster entered service in 1990. Orbital Sciences created a new version of the Pegasus, the Pegasus XL, with stretched first and second stages to enhance the payload capacity of the booster. While the first Pegasus XL launch was in 1994, the first successful Pegasus XL flight did not occur until 1996. The original, or standard, version of the Pegasus was retired in 2000, and only the Pegasus XL is used today. The air-launched nature of the Pegasus permits launches from a number of different facilities, depending on the orbital requirements of the payload. Pegasus launches have been staged from seven sites to date: Edwards Air Force Base (EAFB) and VAFB, California; CCAFS and Kennedy Space Center (KSC), Florida; NASA WFF, Virginia; Kwajalein Missile Range, Marshall Islands; and Gando AFB, Canary Islands.

NASA certified Pegasus to carry the highest value satellites (Category Three Certification) because of its excellent demonstrated reliability record. Pegasus has launched its last 22 missions successfully. One Pegasus XL launched in 2005, carrying the Demonstration of Autonomous Rendezvous Technology (DART) flight demonstrator vehicle for NASA. Three missions are planned for 2006, including Communication/Navigation Outage Forecasting System (C/NOFS), a USAF payload whose launch will be licensed by FAA/AST.

### Taurus - Orbital Sciences Corporation


Taurus launch

The Taurus ELV is a ground-launched vehicle based on the air-launched Pegasus. Orbital Sciences Corporation developed the Taurus under the sponsorship of DARPA to develop a standard launch vehicle to be set up quickly in new locations to launch small satellites that are too large for the Pegasus XL. The Taurus uses the three stages of a Pegasus XL, without wings or stabilizers, stacked atop a Castor 120 solid rocket motor that serves as the Taurus' first stage. The Taurus successfully completed six of seven launch attempts since entering service in 1994. No Taurus launches took place in 2005, and none are currently planned for 2006.

### Titan 4 - Lockheed Martin Corporation


Titan 4 launch

The Titan 4 program dates back to 1985, when the USAF commissioned Martin Marietta (now Lockheed Martin) to develop an upgraded version of the existing Titan 34D ELV that could launch Space Shuttle-class payloads as an alternative to the Shuttle. The Titan 4A was based on the Titan 34D, but it featured stretched first and second stages, two more powerful solid rocket motors, and a larger payload fairing. The Titan 4A was used between 1989 and 1998. The Titan 4B, introduced in 1997, was the most powerful ELV used in the United States for many years until the inaugural flight of the Delta 4 Heavy. Titan 4A used upgraded solid rocket motors that increase the payload capacity of the vehicle by 25 percent. The Titan 4B is used solely for U.S. military payloads, with the exception of the October 1997 launch of NASA's Cassini mission. Titan 4B has been phased out in favor of the heavy Delta 4 and Atlas 5 variants, as the final two Titan 4B missions took place in 2005.

### Zenit 3SL - Sea Launch Company, LLC


Zenit 3SL launch

The Zenit 3SL is a Ukrainian-Russian launch vehicle operated by Sea Launch, a multinational joint venture led by The Boeing Company. Ukrainian companies SDO Yuzhnoye and PO Yuzhmash provide the first two stages. A single engine, using LOX/kerosene propellants, powers each stage. These stages are the same as those used on the Zenit 2 launch vehicle. A Russian company, RSC Energia, provides the third stage, a Block DM-SL upper stage, which also uses LOX/kerosene propellants. Boeing provides the payload fairing, interfaces, and operations management. Boeing Launch Services, Inc., manages marketing and sales.

The Zenit 3SL launches from the Odyssey mobile launch platform, which travels from its home port in Long Beach, California, to a position on the Equator in the Pacific Ocean for each mission. Launch operations are remotely controlled from a separate vessel, the Sea Launch Commander. While Sea Launch conducts commercial launches with a license from FAA/AST, the multinational nature of the system prevents it from carrying U.S. government payloads. Sea Launch completed four launches in 2005 and has five scheduled for 2006.

## ELV Development Efforts

A number of efforts by established corporations and startups are currently in progress to develop new ELVs. The majority of these designs focus on the small payload sector of the launch market, with the goal of placing payloads as small as a few hundred pounds into LEO. A limited market currently exists for such launches, so the success of these vehicles may rely on the ability to reduce launch costs enough to enable new markets.

### Aquarius - Space Systems/Loral

**Vehicle:** Aquarius

**Developer:** Space Systems/Loral

**First Launch:** TBD

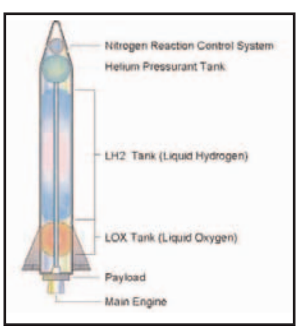
**Number of Stages:** 1

**Payload Performance:** 1,000 kg (2,200 lbs.) to LEO (52-degrees)

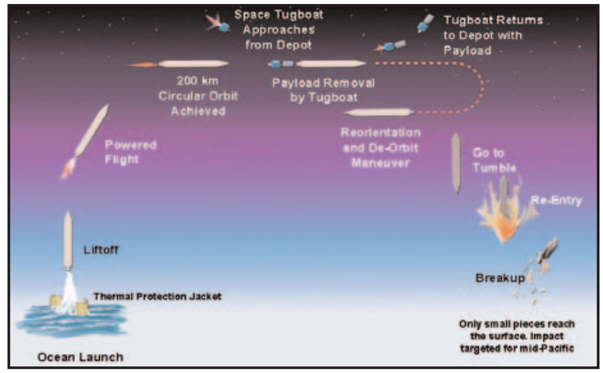
**Launch Site:** Ocean

**Markets Served:** ISS resupply, small satellite launch

Space Systems/Loral of Palo Alto, California, has proposed Aquarius, a low-cost launch vehicle designed to carry small, inexpensive payloads into LEO. This vehicle is primarily intended to launch into orbit bulk products, such as water, fuel, and other consumables, that are inexpensive to replace. As currently designed, Aquarius will be a single-stage vehicle 43 meters (141 feet) high and 4 meters (13.1 feet) in diameter and powered by a single engine using liquid hydrogen and oxygen propellants. The vehicle is floated in the ocean before launch to minimize launch infrastructure and will be able to place a 1,000-kilogram (2,200-pound) payload into a 200-kilometer (125-mile), 52-degree orbit. Located in the base of the vehicle, the payload will be extracted by an orbiting space tug for transfer to its ultimate destination. After payload extraction is completed, the vehicle will deorbit and be destroyed. Launch costs are planned to be $1-2 million a flight.



Aquarius



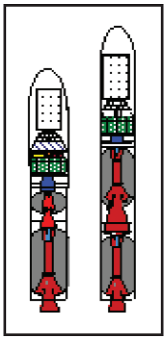
Aquarius mission profile

Previous work on Aquarius includes a study of the launch concept funded by the California Space Authority in 2002. In 2005 Space Systems/Loral, in conjunction with Aerojet, a GenCorp Company based in Sacramento, and ORBITEC of Madison, Wisconsin, started work on a $1-million study funded by a provision of a defense appropriations bill on new engine technologies for use on Aquarius. The study is focusing on the development of a vortex combustion cold wall engine, using LOX and liquid hydrogen propellants; the engine would provide high thrust while eliminating the need for costly ablative materials in engine components. The study is scheduled to conclude in 2006.[4]

### Eagle S-series - E'Prime Aerospace Corporation

E'Prime Aerospace of Titusville, Florida, is developing a family of launch vehicles, called the Eagle S-series, based on the LGM-118A Peacekeeper ICBM design. Like the Peacekeeper, this vehicle will be ejected from a ground-based silo, using a compressed gas system. At an altitude of 61 meters (200 feet), the vehicle's engines will ignite. The smallest vehicle, the Eaglet, could launch 580 kilograms (1,280 pounds) into LEO. A somewhat larger version, the Eagle, could put 1,360 kilograms (3,000 pounds) into LEO. Both vehicles will use solid propellant lower stages and liquid pro-

**Vehicle:** Eaglet/Eagle
**Developer:** E'Prime Aerospace
**First Launch:** TBD
**Number of Stages:** 2
**Payload Performance:** 580 kg (1,280 lbs.) to LEO (Eaglet); 1,360 kg (3,000 lbs.) to LEO (Eagle)
**Launch Sites:** KSC, WFF, CCAFS, Kodiak
**Market Served:** Small satellite launch



Eaglet and Eagle

pellant upper stages. E'Prime has also proposed larger vehicles, designated S-1 through S-7, with the ability to place considerably larger payloads into LEO and to add a geosynchronous Earth orbit (GEO) capability. The Eagle S-series concept dates back to 1987 when the company signed a commercialization agreement with the USAF to use Peacekeeper technology for commercial launch vehicles.

E'Prime signed an agreement with NASA in February 2001 that gives the company use of available property and services on a non-interference basis. For equatorial orbits, the company plans to launch the Eaglet and Eagle, and the company's entire canister launch program from facilities at NASA KSC that the company has yet to construct. Plans to launch from Virginia Space Flight Center for equatorial orbits and from the Kodiak Launch Complex for polar orbits are also under consideration. In 2004, the company entered into a partnership with the Savannah River National Laboratory to develop technologies for the Eagle S-series of launch vehicles and related systems.[5]

### FALCON SLV - Lockheed Martin

FALCON

Lockheed Martin Michoud Operations of New Orleans, Louisiana was awarded one of four DARPA Force Application and Launch from CONUS (FALCON) contracts, valued at $11.7 million, in September 2004 to develop concepts for a low-cost launch vehicle.[6] Lockheed Martin's FALCON SLV approach uses all-hybrid propulsion and a mobile launch system that can launch from an unimproved site with limited infrastructure on 24 hours notice,

**Vehicle:** FALCON SLV
**Developer:** Lockheed Martin Michoud Operations
**First Launch:** TBD
**Number of Stages:** 2
**Payload Performance:** 840 kg (1,855 lbs.) to LEO
**Launch Site:** TBD
**Markets Served:** Small satellite launch, responsive space operations

placing up to 840 kilograms (1,855 pounds) into LEO. Lockheed conducted two test firings of the hybrid rocket motor that will be used on the upper stage of the SLV in 2005. DARPA is expected to award a contract no later than 2007 to develop a concept through flight tests.[7]

### Nanosat Launch Vehicle - Garvey Spacecraft Corporation

**Vehicle:** Nanosat Launch Vehicle
**Developer:** Garvey Spacecraft Corporation
**First Launch:** TBD
**Number of Stages:** 2
**Payload Performance:** 10 kg (22 lbs.) to LEO
**Launch Site:** TBD
**Market Served:** Nanosatellite launch

NLV

Garvey Spacecraft Corporation (GSC), based in Long Beach, California, is a small research and development (R&D) company, focusing on the development of advanced space technologies and launch vehicle systems. As part of the California Launch Vehicle Initiative (CALVEIN), GSC and California State University, Long Beach (CSULB), are jointly conducting preliminary R&D tasks to establish the foundation for development of a two-stage, liquid propellant Nanosat Launch Vehicle (NLV). Capable of delivering 10 kilograms (22 pounds) to a 250-kilometer (155-mile) polar orbit, the NLV will provide low-cost, dedicated launch services to universities and other research organizations that traditionally depend on secondary payload opportunities to access space. As part of this initiative, GSC and CSULB are pursuing advanced aerospike engine technology for use on the NLV first stage. Their current work builds upon the first-ever powered liquid propellant aerospike flight that the team conducted using several of its LOX/ethanol Prospector research vehicles. GSC's most visible accomplishments include the first-ever flight of a composite LOX tank (conducted in partnership with Microcosm, Inc.), the first-ever powered flights of a liquid-propellant aerospike engine, and the launch and 100-percent recovery of several prototype reusable test vehicles.

On May 24, 2005, GSC and CSULB conducted a successful test launch of Prospector 6, a partially-reusable full-scale prototype of the NLV, from the Mojave Test Area in California. The rocket flew to an altitude of approximately 915 meters (3,000 feet) before parachuting back to Earth. The GSC/CSULB team is planning to refurbish and relaunch the rocket while also working on an improved design. In October 2005, GSC and CSULB conducted two flights in the same day of a single vehicle, the new Prospector 7, to demonstrate RLV-like rapid turnaround operations. At present, project funding is derived from a series of NLV-related suborbital flight tests that GSC and CSULB are conducting for several U.S. government organizations.[8]

### Eagle SLV - Microcosm, Inc.

**Vehicle:** Eagle SLV

**Developer:** Microcosm, Inc.

**First Launch:** TBD

**Number of Stages:** 3

**Payload Performance:** 670 kg (1,470 lbs.) to LEO, 330 kg (730 lbs.) to SSO

**Launch Sites:** VAFB, WFF, CCAFS

**Markets Served:** Small satellite launch, responsive space operations

Eagle SLV

Microcosm, Inc. of El Segundo, California, is developing the Scorpius family of ELVs. Several prototypes are under consideration or in testing, and two suborbital test models, SR-S and SR-XM-1, flew successfully from White Sands Missile Range, New Mexico, in 1999 and 2001, respectively. Eventually Microcosm plans to market up to eight Scorpius variants: two suborbital vehicles, the SR-S and SR-M launchers; three light-lift orbital vehicles, the Sprite Mini-Lift, the Eagle SLV, and the Liberty Light-Lift launchers; one intermediate-lift orbital vehicle, the Antares Intermediate-Lift launcher; one medium-lift vehicle, the Exodus Medium-Lift launcher; and one heavy-lift vehicle, the Space Freighter. Despite the wide range in their sizes and lift capacities, each Scorpius variant is based on a scaleable modular design featuring simple LOX/Jet-A pressure-fed motors without turbopumps and low-cost avionics equipped with GPS/INS (global positioning system/inertial navigation system). The orbital variants are three stages and feature thick fuel tanks for added durability during flight.

The Scorpius system is designed simply in order to maximize the cost savings and quick launch pad turnaround times sought by government-sponsored responsive space initiatives. As a first step, the test launches of the suborbital SR-S and SR-XM-1 vehicles demonstrated Scorpius' ability to be ready for flight within 8 hours of arrival at the launch pad, using a crew of under 15. When marketed, the SR-S vehicle is advertised as able to loft 200 kilograms (440 pounds) suborbitally. The SR-M would loft 1,089 kilograms (2,400 pounds) suborbitally.

The Sprite Mini-Lift vehicle is projected to loft up to 318 kilograms (700 pounds) to LEO. Eagle SLV would loft up to 670 kilograms (1,470 pounds) to LEO. The Liberty Light Lift vehicle would loft up to 1,270 kilograms (2,800 pounds) to LEO.

Microcosm's intermediate-, medium-, and heavy-lift Scorpius variants will be able deploy payloads to LEO and GTO. The Antares Intermediate-Lift vehicle will be able to deploy up to 2,676 kilograms (5,900 pounds) to LEO and up to 885 kilograms (1,950 pounds) to GTO. The Exodus Medium-Lift vehicle would deploy up to 6,713 kilograms (14,800 pounds) to LEO and up to 2327 kilograms (5,130 pounds) to GTO. Specifications for the heavy-lift Space Freighter are not yet available.

Microcosm received one of four contracts, valued at $10.5 million, from DARPA in September 2004 for phase 2 of the FALCON small launch vehicle program to support development of the Eagle SLV. However, the company was notified in August 2005 that it had not been selected for further work on the program. The company is continuing development of the Scorpius vehicle concept under a separate Defense Department contract.

### QuickReach - AirLaunch, LLC

**Vehicle:** QuickReach
**Developer:** AirLaunch, LLC
**First Launch:** TBD
**Number of Stages:** 3 (including the launch aircraft)
**Payload Performance:** 450 kg (1,000 lbs.) to LEO
**Launch Site:** Air launched
**Markets Served:** Small satellite launch, responsive space operations

QuickReach

AirLaunch, LLC, based in Kirkland, Washington, is leading the development of a small, low-cost air-launched vehicle for defense and other applications. The two-stage rocket is carried aloft inside a cargo aircraft, such as a C-17 or Antonov-124. The rocket is released from the aircraft at an altitude of 7,600-10,700 meters (25,000-35,000 feet) and fires its liquid-propellant engines to ascend to orbit. The vehicle is designed to place a 450-kilogram (1,000-pound) payload into LEO for less than $5 million.

AirLaunch received one of four Phase 2 FALCON small launch vehicle contracts, valued at $11.4 million, from DARPA in September 2004 to continue development of the concept. The company performed tests of the booster deployment system as well as ground tests of a liquid oxygen-propane engine, capable of producing 107,000 newtons (24,000 pounds-force), intended for the vehicle's upper stage. The company is awaiting a decision from DARPA on the next stage of the program.[9]

### SLC-1 - Space Launch Corporation

The Space Launch Corporation of Irvine, California, is in the initial development stages of its SLC-1 launch system. The SLC-1 would use an expendable rocket air-launched from an F-4 aircraft. The aircraft's jet engines would be modified using a technology called Mass Injected Pre-Compressor Cooling (MIPCC), where a coolant such as water or liquid oxygen is added to the air at the engine inlet, allowing the engine to operate at higher altitudes than possible. The SLC-1 system could launch payloads of 10 to 20 kilograms (22 to 44 pounds) into LEO for $1 million a launch. The company is seeking funding from the Defense Department to support development of the vehicle.[10]

**Vehicle:** SLC-1
**Developer:** Space Launch Corporation
**First Launch:** TBD
**Number of Stages:** 3 (including the launch aircraft)
**Payload Performance:** 10-20 kg (22-44 lbs.) to LEO
**Launch Site:** Air launched
**Markets Served:** Small satellite launch, responsive space operations

The Space Launch Corporation was also selected as the sole prime contractor for DARPA's Responsive Access, Small Cargo, Affordable Launch (RASCAL) program in March 2003. RASCAL was intended to develop a new air-launch tactical launch system, similar to SLC-1 but larger, that will provide the U.S. military with the ability to launch time critical space-based assets within hours of detection of an emerging threat. In November 2004, the Space Launch Corporation announced successful completion of the second phase of the DARPA RASCAL program, which was intended to advance the design of the RASCAL system concept and mitigate the technical risks identified in Phase 1. However, DARPA elected in 2005 not to proceed with the next phase of the program.[11]

### Zenit 3SLB - Sea Launch Company, LLC, and Space International Services

**Vehicle:** Zenit 3SLB
**Developer:** Space International Services
**First Launch:** 2nd quarter 2007
**Number of Stages:** 3
**Payload Performance:** 3,500 kg (7,720 lbs.) to GTO
**Launch Site:** Baikonur
**Market Served:** Commercial GEO satellite launch

The Sea Launch Board of Directors voted on September 30, 2003, to offer launch services from Baikonur Cosmodrome in Kazakhstan, in addition to its sea-based launches at the Equator. The new offering, Land Launch, is based on the collaboration of Sea Launch Company and Space International Services, of Russia, to meet the launch needs of commercial customers with medium weight satellites.

Zenit 3SLB

The Land Launch system uses a version of the Sea Launch Zenit-3SL rocket, the Zenit 3SLB, to lift commercial satellites in the 2,000 to 3,500-kilogram (4,410 to 7,720-pound) range to GTO and heavier payloads to inclined or lower orbits. The three stages on the Zenit 3SLB are the same as those on the Sea Launch Zenit-3SL, with the only significant difference between two being the fairing. A two-stage configuration of the same rocket, the Zenit 2SLB, is also available for launching heavy payloads, or groups of payloads, to LEO. Payloads and vehicles will be processed and launched from existing Zenit facilities at the Baikonur launch site. The first Land Launch mission, carrying the PAS-11 satellite for PanAmSat, is scheduled for the second quarter of 2007.[12] Expanding on its Sea Launch marketing efforts, Boeing Launch Services, Inc., manages marketing and sales for this new offering.

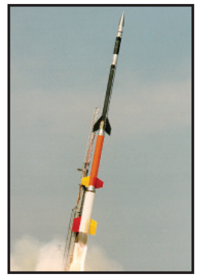
## NASA Exploration Launch Vehicles

On September 19, 2005, NASA announced its planned mission architecture for crewed lunar missions. The plan calls for the development of two new launch vehicles. One, a crew launch vehicle, will be used to launch the Crew Exploration Vehicle (CEV). It will use a standard Space Shuttle solid rocket booster as its first stage, and a liquid hydrogen/liquid oxygen upper stage, powered by a single Space Shuttle Main Engine (SSME). A separate heavy-lift launch vehicle will be used to launch cargos weighing up to 125 metric tons into LEO. It will use a main stage derived from the Space Shuttle external tank with five SSMEs at its base. It will also use two five-segment solid rocket boosters, extended versions of those used for the Shuttle today. NASA has not published additional technical details about these vehicles, nor schedules for their development.[13]

## Sounding Rockets

In addition to orbital launch vehicles, a number of suborbital ELVs, or sounding rockets, are in use today. These vehicles, which use solid propellants, support a variety of applications, including astronomical observations, atmospheric research, and microgravity experiments.

### Black Brant - Bristol Aerospace Limited (a Magellan Aerospace Company)



Black Brant launch

Over 800 Black Brant rockets have been launched since 1962, when manufacture of the vehicle began. Versions of the Black Brant can carry payloads ranging from 70 to 850 kilograms (154 to 1,874 pounds) to altitudes from 150 to more than 1,500 kilometers (93 to 932 miles), and can provide up to 20 minutes of microgravity time during a flight. The Black Brant and Nihka motors used on some Black Brant versions are manufactured in Canada by Bristol Aerospace Limited (a Magellan Aerospace Company). The Nike, Talos, and Taurus motors used on other Black Brant versions are built in the United States. These vehicles are integrated by the launch operator. In the United States, NASA has been a frequent user of Black Brant vehicles.

The smallest version of the Black Brant family is the single-stage Black Brant 5, which is 533 centimeters (210 inches) long and 43.8 centimeters (17.24 inches) in diameter. The rocket produces an average thrust of 75,731 newtons (17,025 pounds-force). The Black Brant 5 motor is used as the second or third stage in larger, multi-stage versions of the Black Brant. The most powerful, Black Brant 12, is a four-stage vehicle that uses the Black Brant 5 motor as its third stage. This vehicle can launch a 113-kilogram (249-pound) payload to an altitude of at least 1,400 kilometers (870 miles), or a 454-kilogram (1,001-pound) payload to an altitude of at least 400 kilometers (249 miles).

### Oriole - DTI Associates

Oriole

SPACEHAB's Astrotech Space Operations developed the Oriole sounding rocket in the late 1990s to provide launch services for commercial and scientific payloads. Oriole was both the first privately developed sounding rocket in the United States and the first new U.S. sounding rocket in 25 years. The Oriole is a single-stage vehicle with a graphite-epoxy motor manufactured by Alliant Missile Products Company of Rocket Center, West Virginia. It is 396 centimeters (156 inches) long, 56 centimeters (22 inches) in diameter, and generates an average thrust of 92,100 newtons (20,700 pounds-force). The vehicle provides payloads with 6 to 9 minutes of microgravity during flight. Additionally, it can be combined with other motors to create two-stage sounding rockets (with the Oriole serving as the second stage).

On July 7, 2000, the first Oriole launch took place from NASA WFF. The launch used a two-stage configuration, with the Oriole serving as the second stage and a Terrier Mk 12 motor serving as the first stage. The Oriole sounding rocket reached a peak altitude of 385.6 kilometers (229 miles) 315 seconds after launch during the 10-minute test flight.

In July 2001, SPACEHAB's Astrotech Space Operations sold the Oriole program to DTI Associates of Arlington, Virginia, which integrates the vehicle and offers it commercially.

### Terrier-Orion - DTI Associates

Terrier-Orion

The Terrier-Orion is a two-stage, spin-stabilized sounding rocket. It uses a Terrier Mk 12 Mod 1 engine for its first stage and an improved Orion motor for its second stage. The Terrier Mk Mod 1 is a surplus U.S. Navy missile motor; Orion is a surplus U.S. Army missile motor. The Terrier-Orion is 10.7 meters (35.1 feet) long. The Terrier stage is 46 centimeters (18 inches) in diameter, and the Orion is 36 centimeters (14 inches) in diameter. The Terrier-Orion can loft payloads weighing up to 290 kilograms (639 pounds) to altitudes up to 190 kilometers (118 miles).

A more powerful version of the Terrier-Orion rocket uses the Terrier Mk 70 motor as its first stage. This version was used for two FAA/AST-licensed suborbital launches performed by Astrotech Space Operations/DTI at the Woomera Instrumented Range in Australia in 2001 and 2002. The second flight, in July 2002, successfully flew the HyShot scramjet engine experiment.

DTI Associates of Arlington, Virginia, now markets and offers integration services for the Terrier-Orion after purchasing all intellectual property rights to the rocket from SPACEHAB in July 2001.

### Hybrid Sounding Rocket Program - Lockheed Martin-Michoud

HYSR

Lockheed Martin-Michoud is developing a hybrid sounding rocket (HYSR) program with NASA Marshall Space Flight Center (MSFC). A Space Act Agreement between NASA MSFC and Lockheed Martin-Michoud Operations enabled collaboration on this new technology. Development ground testing (hardware qualification) occurred at NASA Stennis Space Center between 2000 and 2001. This testing concluded with a successful demonstration flight of a prototype sounding rocket from NASA WFF in December 2002. The flight demonstration vehicle was a 17.4-meter (57-foot) long sounding rocket using liquid oxygen and solid fuel, a rubberized compound known as hydroxyl terminated polybutadiene (HTPB). The rocket generated 27,216 kilograms (60,000 pounds) of thrust during a burn time of 31 seconds, and reached an altitude of approximately 43 miles.

In 2004, there was further testing of the HYSR motors at NASA Stennis Space Center. The tests demonstrated the structural integrity of Lockheed Martin-Michoud's fuel-grain design and are facilitating development of advanced state-of-the-art hybrid rocket motors.

### Norwegian Sounding Rocket Program - Lockheed Martin-Michoud

Lockheed Martin-Michoud is also engaged in the Pantera Program, which provides a laser-enabled in-flight targeting system for Norway's air force. The single-stage rocket will be built by the Norwegian company Nammo Raufoss AS, but the design, engineering schematics, and vehicle assembly plan will be provided by Lockheed Martin-Michoud. The hybrid rocket will use liquid oxygen and rubberized HTPB as fuel. It will have a 3,175-kilogram (7,000-pound) thrust and a burn time of 30 to 35 seconds. Its peak altitude is expected to be between 55 and 75 kilometers (34 and 57 miles). Lockheed Martin-Michoud obtained an International Traffic in Arms Regulations (ITAR) Manufacturing License Agreement from the U.S. Government to gain approval for the 17-month design and handoff project. A successful 20-second static firing of the rocket engine took place August 30, 2005 at Nammo Raufoss's test facility in Raufoss, Norway.[14]

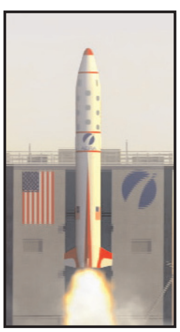
# Reusable Launch Vehicles

This section describes active and emerging RLV programs in the United States. Emphasis is placed on vehicles being developed by private companies without the assistance of the government. Many of these companies are developing space hardware for the first time. Government RLV programs are also included to provide context, particularly since the Space Shuttle is considered a first-generation RLV and is a precursor of what may become a long line of government next-generation systems. Experiences gained by operating the Space Shuttle for more than 20 years have helped solve, as well as highlight, crucial problems related to the design of efficient RLV systems. The first section addresses commercial RLV projects underway or in development. A discussion of government RLV development efforts comprises the balance of this section.

## Commercial RLV Development Efforts

### Altairis - AeraSpaceTours

**Vehicle:** Altairis
**Developer:** AERA
**First Launch:** December 2006
**Number of Stages:** 2
**Payload:** 7 people to 100 km
**Possible Launch Site:** CCAFS
**Targeted Market:** Suborbital space tourism



Altaris

Founded in 2002, AeraSpaceTours, a division of Sprague Astronautics, is planning the development of Altairis, a rocket utilizing RP-1/LOX propulsion. Altairis launches vertically and has the capability of sending seven passengers to space. AeraSpaceTours plans Altairis to be a generation of spacecraft that are produced on an ongoing basis on a production line. AERA anticipates having the first Altairis completed in 2006 with approximately one new Altairis vehicle produced each month thereafter. AeraSpaceTours foresees providing spaceflights starting in late 2006 at CCAFS.

On March 7, 2005, AeraSpaceTours signed a "Commercial Space Operations Support Agreement" with the USAF. This agreement ascertains the ground-rules intended for AeraSpaceTours' proposed access of the launch facilities and support services at CCAFS. The agreement is effective for five years and renewable thereafter.

### Black Armadillo - Armadillo Aerospace

**Vehicle:** Black Armadillo
**Developer:** Armadillo Aerospace
**First Launch:** 2006
**Number of Stages:** 1
**Payload:** TBD
**Possible Launch Site:** White Sands
**Targeted Market:** Suborbital spaceflight

Black Armadillo

Armadillo Aerospace, a former competitor for the Ansari X Prize, is continuing development of suborbital, piloted spacecraft. The company has built a subscale demonstrator of a proposed one-person suborbital spacecraft, a conical vehicle three meters (10 feet) tall and powered by a LOX/ethanol engine. Armadillo Aerospace conductedan unmanned low-level test flight of the demonstrator at the X Prize Cup Exhibition in Las Cruces, New Mexico, in October 2005. A full-scale vehicle may be ready for suborbital spaceflight from White Sands, New Mexico as early as 2006. Armadillo's founder, John Carmack, has invested $2.5 million into the venture over the last five years.[15]

### New Shepard - Blue Origin

**Vehicle:** New Shepard
**Developer:** Blue Origin
**First Launch:** 4th quarter 2006
**Number of Stages:** TBD
**Payload:** TBD
**Possible Launch Site:** Culberson County, Texas
**Targeted Market:** Suborbital space tourism

Blue Origin is progressing with their vehicle developments and technology. Blue Origin intends to pursue these developments to facilitate human presence in space. Their initial research efforts are focused on reusable liquid propulsion systems, low cost operations, life support, abort systems, and human factors. They are currently working to develop a crewed, suborbital launch system that emphasizes safety while minimizing the cost of operations.

Blue Origin proposes to develop a launch facility to operate its RLV, which is expected to carry paying passengers on suborbital ballistic trajectories to altitudes in excess of 100 kilometers (62 miles). Blue Origin's preliminary plan includes a propulsion module, crew capsule, and the use of hydrogen peroxide and kerosene as propellants. In addition to the RLV launching and landing vertically, it would be fully reusable and would operate autonomously under the control of on-board computers, with no ground control during nominal flight conditions.

On June 14, 2005, Blue Origin held a meeting to outline some future plans in order to request from FAA/AST a license to operate.[16]

### Sea Star - Interorbital Systems

**Vehicle:** Sea Star MSLV
**Developer:** Interorbital Systems
**First Launch:** 2007
**Number of Stages:** 11/2
**Payload:** 13 kg (30 lbs.) to LEO
**Possible Launch Sites:** Pacific Ocean just west of Los Angeles, California; Tonga
**Targeted Market:** Microsatellite launches

Interorbital Systems (IOS) of Mojave, California, is developing the Sea Star MSLV microsatellite launch vehicle for microsatellite payloads weighing up to 13 kilograms (30 pounds) and as a testbed for its larger Neptune orbital launch vehicle. These vehicles are constructed for design simplicity. Sea Star MSLV is a "stage-and-a-half" design, similar to the older Atlas rockets, with a single large booster engine in a module attached to the aft end of the main structure-jettisoned during ascent-and four smaller vernier engines on the main structure. All the engines use liquid oxygen and liquid natural gas (LNG) as propellants. The main structures of the rocket, including the outer shell and propellant tanks, will use carbon composite materials.

Sea Star does not require land-based launch infrastructure. Taking advantage of design elements derived from submarine-launched ballistic missiles, this vehicle will float in seawater and launch directly from the ocean. IOS plans to launch Sea Star MSLV near California or in waters near the Kingdom of Tonga, with an initial launch planned for 2007.

### Neptune - Interorbital Systems

**Vehicle:** Neptune
**Developer:** Interorbital Systems
**First Launch:** 2008
**Number of Stages:** 11/2
**Payload:** 4,500 kg (10,000 lbs.) to LEO
**Possible Launch Sites:** Pacific Ocean just west of Los Angeles, California; Tonga
**Targeted Market:** Orbital space tourism


Neptune

IOS' Neptune is a scaled-up version of its Sea Star rocket and is intended to carry passengers into orbit. The Neptune uses the same stage-and-a-half design of the Sea Star, with a large engine in a booster module and four smaller vernier engines attached to the main vehicle structure. The engines are larger versions of the LOX/LNG engines developed for Sea Star, generating a total of 2.5 million newtons (560,000 pounds-force.) of thrust at liftoff. The vehicle can place 4,500 kilograms (10,000 pounds) into a 51-degree 400-kilometer (250-mile) orbit.

A unique aspect of the Neptune is that the main rocket structure, once in orbit, can act as a small space station. A conical crew module attached to the top of the rocket, carrying up to five people, would undock, turn 180 degrees, and dock nose-first with the orbital station module. The module's two LOX tanks, each spheres six meters (20 feet) in diameter, would be purged of any remaining propellant and then pressurized to serve as habitation modules. IOS plans to use the Neptune to serve the orbital space tourism market, selling week-long trips for $2 million per person starting in 2008.[17]

### K-1 - Kistler Aerospace Corporation

**Vehicle:** K-1

**Developer:** Kistler Aerospace Corporation

**First Launch:** 2007

**Number of Stages:** 2

**Payload:** 5,700 kg (12,500 lbs) to LEO; 3,200 kg (7,000 lbs) to ISS and 900 kg (2,000 lbs) from ISS; 1,570 kg (3,460 lbs) to GTO, 900-1,400 kg (2,000-3,000 lbs) to interplanetary targets

**Possible Launch Sites:** Woomera, Australia; Nevada Test Site

**Targeted Markets:** Development of payloads to LEO, MEO, and GTO; interplanetary orbits (with K-1 Active Dispenser); ISS cargo re-supply and return missions.

K-1

Kistler Aerospace Corporation has been developing the fully reusable K-1 for launches of government and commercial payloads to orbit. The first vehicle is 75 percent complete. The K-1 design was developed in the mid-1990s as a two-stage-to-orbit (TSTO) vehicle with a payload capacity of approximately 5,700 kilograms (12,500 pounds) to LEO. The K-1 will be able to launch multiple small payloads and conduct technology demonstrations on dedicated LEO missions or as secondary payloads.

Kistler has completed a conceptual design for an Active Dispenser that will deploy payloads to medium Earth orbits (MEO), GTO, and interplanetary trajectories. The Active Dispenser will expand the K-1's capability beyond LEO (approximately 1,570 kilograms (3,462 pounds) to GTO or 900 to 1,400 kilograms (2,000 to 3,000 pounds) to interplanetary targets). The K-1's inherent reusability enables it to provide cargo re-supply and return services for the International Space Station (ISS), delivering approximately 3,200 kilograms (7,000 pounds) up-mass and recovering a minimum of 900 kilograms (2,000 pounds) down-mass to the launch site. The K-1 will launch vertically like a conventional ELV, but it will use a unique combination of parachutes and air bags to recover its two stages. Designed to operate with a small complement of ground personnel, this vehicle will be transported to the launch site and erected with a mobile transporter. The K-1 will measure approximately 37 meters (121 feet) in height and have a launch mass of 382,300 kilograms (843,000 pounds).

The K-1 employs off-the-shelf technology and components in its design. The first stage, known as the Launch Assist Platform (LAP), is powered by three LOX/kerosene GenCorp Aerojet AJ26 engines. These engines are U.S. modifications of the fully developed, extensively tested core of the NK-33/NK-43 engines. These engines were originally designed for the Soviet lunar program in the 1960s and subsequently placed in storage for over two decades. After launch, the LAP separates from the second stage and restarts its center engine to put the stage on a return trajectory to a landing area near the launch site. The LAP deploys parachutes and descends to the landing area where air bags are deployed to cushion its landing. The second stage, or orbital vehicle, continues into LEO where it releases its payload. A single Aerojet AJ26-60 engine powers the orbital vehicle. Following payload separation, the orbital vehicle continues on orbit for approximately 24 hours. Then, a LOX/ethanol Orbital Maneuvering System performs a deorbit burn. Lastly, the orbital vehicle ends its ballistic reentry profile by deploying parachutes and air bags in a manner similar to the LAP.

Kistler expects to operate the K-1 from two launch sites: Woomera, Australia, and a U.S. domestic launch site. Kistler Woomera Pty., Ltd., a wholly owned subsidiary of Kistler Aerospace Corporation, will operate the K-1 from Woomera. Kistler received authorization from the Australian government to begin construction of launch facilities at Woomera in April 1998 and held a groundbreaking ceremony at the site several months later. The launch pad design is complete, and Kistler will conduct its initial K-1 flights and commercial operations from Woomera. In 1998, Kistler signed an agreement with the Nevada Test Site Development Corporation to permit Kistler to occupy a segment of the U.S. Department of Energy's Nevada Test Site for its launch operations. The FAA/AST environmental review process was completed for the Kistler project in 2002. In addition, Kistler continues to explore potential U.S. launch and landing sites (subject to regulatory approval), such as at CCAFS, VAFB, and EAFB.

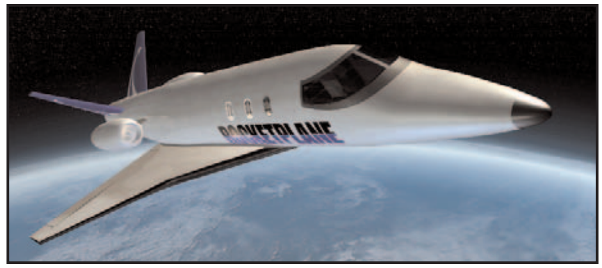
In 2005 Kistler completed its reorganization under Chapter 11 of the U.S. Bankruptcy Code, which it had been under since 2003. However, in September 2005, Bay Harbour Management, the investment company that had been supporting Kistler during its bankruptcy reorganization, said that it was "radically reducing" its investment because of delays in a NASA program to commercially procure ISS cargo services.[18]

### Rocketplane XP - Rocketplane, Inc.

**Vehicle:** Rocketplane XP
**Developer:** Rocketplane, Inc.
**First Launch:** 2007
**Number of Stages:** 1
**Payload:** 400 kg (880 lbs.) to 100 km
**Possible Launch Site:** Oklahoma Spaceport
**Targeted Markets:** Space tourism, microgravity research

Rocketplane Limited is developing the Rocketplane XP, a scaled-down version of its original Pathfinder vehicle concept. The Rocketplane XP is a four-seat vehicle based on a Lear jet, powered by two jet engines and one Rocketdyne RS-88 LOX/kerosene rocket engine, capable of 160,000 newtons (36,000 pounds-force.) of thrust. The Rocketplane XP would take off from an airport under jet power, fly to an altitude of 5,500 to 9,100 meters (18,000 to 30,000 feet), then ignite the engine for a 90-second burn, carrying the vehicle to an altitude of at least 100 kilometers (62 miles). The vehicle would then fly back to a landing at the same site as takeoff.

In 2004, Rocketplane Limited signed a marketing agreement with Incredible Adventures to sell suborbital tourist flights. The company is currently



Rocketplane XP

taking reservations for Rocketplane flights and hopes to make its first tourist flight in 2007. The spaceflight experience as currently envisioned includes five days of training and team social events, with the spaceflight on the sixth day. In addition to space tourism flights, the company is pursuing other markets, including microgravity research and military applications, including small satellite deployment.

### SpaceShipOne - Scaled Composites, LLC

**Vehicle:** SpaceShipOne
**Developer:** Scaled Composites
**First Launch:** 2003
**Number of Stages:** 1
**Payload:** 3 people to 100 km
**Launch Site:** Mojave Airport
**Targeted Market:** Research and development

SpaceShipOne

Scaled Composites, the winner of the Ansari X Prize, and the team that made the first non-governmental manned-rocket flight to suborbital space, unveiled its vehicle on April 18, 2003. SpaceShipOne is a three-person vehicle designed to be air-launched at an altitude of 15,240 meters (50,000 feet) from a carrier aircraft, called White Knight. On April 1, 2004, FAA/AST issued the first commercial RLV mission-specific launch license (LRLS 04-067) to Scaled. Including the September 29 and October 4 Ansari X Prize-winning flights, SpaceShipOne successfully completed five licensed flights in 2004.

SpaceShipOne, having served its purpose of testing technologies required for safe, affordable suborbital passenger spaceflight, was retired after winning the Ansari X Prize. Scaled Composites flew SpaceShipOne and White Knight to the Experimental Aircraft Association's annual AirVenture air show in Oshkosh, Wisconsin, in July 2005, where the vehicle was on public display. SpaceShipOne was later flown to Washington, DC, and put on permanent display in the Milestones of Flight gallery in the National Air and Space Museum on October 5, 2005.

### SpaceShipTwo - Scaled Composites, LLC/Virgin Galactic

**Vehicle:** SpaceShipTwo
**Developer:** Scaled Composites
**First Launch:** 2008
**Number of Stages:** 1
**Payload:** 7 people to 100 km
**Possible Launch Sites:** Mojave Airport; SRS
**Targeted Market:** Suborbital space tourism

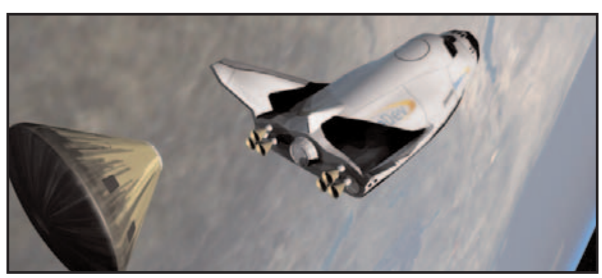
In July 2005 Scaled Composites and Virgin Galactic, a subsidiary of the Virgin Group of Companies, announced the formation of a joint venture called The Spaceship Company. The purpose of The Spaceship Company is to oversee the development and production of SpaceShipTwo, a commercial suborbital spacecraft based on technology developed for SpaceShipOne. The joint venture will contract out the production of up to five SpaceShipTwo vehicles to Scaled Composites; those vehicles will be sold to Virgin Galactic, which plans to put them into commercial service offering suborbital space tourism flights starting in 2008. The venture will also develop a carrier aircraft, White Knight 2, that will be used to air-launch SpaceShipTwo in much the same manner that the original White Knight aircraft air-launched SpaceShipOne. Few technical details about SpaceShipTwo have been released, but the spacecraft is believed to be a scaled-up version of SpaceShipOne, capable of carrying 7-8 people on suborbital spaceflights to altitudes of 100 kilometers (62 miles) or more.[19]

### Dream Chaser - SpaceDev

**Vehicle:** Dream Chaser
**Developer:** SpaceDev
**First Launch:** Sub-orbital test flights by 2008, and manned test flights to orbit by 2010
**Number of Stages:** 1 for suborbital, 2 for orbital
**Payload:** 6 people
**Possible Launch Sites:** TBD
**Targeted Markets:** Suborbital space tourism, ISS crew access

SpaceDev unveiled its plans for Dream Chaser, a suborbital RLV modeled after NASA's X-34, in September 2004. However, in November 2005 the company released a completely new design for the vehicle, incorporating an orbital flight capability for ISS crew transport while retaining the ability to perform suborbital flights. The new design has a relatively long history, as it is based on the NASA HL-20 spaceplane concept from the early 1990s, which was itself inspired by the successfully launched Soviet BOR-4 spaceplane from the early 1980s. Dream Chaser keeps the overall length of 8.84 m (29 feet) and span across the wing tips of 7.16 m (23.5 feet) of the HL-20, but decreases the number of passengers from 10 to 6 and reduces the mass to below 10,000 kilograms (22,046 pounds.)

Dream Chaser is designed to both serve the suborbital tourism market and provide commercial ISS crew transfer. The spacecraft will use internal hybrid rocket motors for suborbital flights, and launch on the side of three large hybrid boosters to reach orbit. SpaceDev is seeking funding to develop Dream Chaser, and could begin suborbital test flights of the vehicle as early as 2008.



Dream Chaser

### Falcon 1 - Space Exploration Technologies Corporation

**Vehicle:** Falcon 1
**Developer:** Space Exploration Technologies Corporation
**First Launch:** 2005
**Number of Stages:** 2
**Payload:** 570 kg (1,255 lbs.) to LEO
**Possible Launch Sites:** Kwajalein Atoll, VAFB
**Targeted Market:** Small satellite launch


Falcon 1

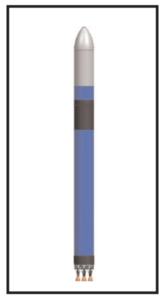
Space Exploration Technologies Corporation (SpaceX) of El Segundo, California, is developing the partially reusable Falcon 1 launch vehicle, which can place up to 570 kilograms (1,255 pounds) into LEO, for about $6 million, a fraction of the cost of other launch vehicles. The first stage of this vehicle is designed to be recovered from the ocean after a parachute landing, refurbished, and reused.

Falcon's first launch took place in December 2005, carrying the FalconSat-2 microsatellite into orbit from SpaceX's launch site on Omelek Island in the Kwajalein Atoll in the Pacific Ocean. SpaceX anticipates two to three launches annually, eventually ramping up to five or six flights a year. SpaceX is privately developing the entire two-stage vehicle from the ground up, including the engines, cryogenic tank structure, and guidance system. The SpaceX-developed first stage engine, known as Merlin, uses pump-driven LOX/kerosene. The second stage engine, called Kestrel, uses a pressure-fed LOX/kerosene system.

In September 2004, SpaceX was one of four companies to receive a contract from DARPA and the USAF to demonstrate low-cost, highly responsive launch technology. Under this $8-millon contract, SpaceX will demonstrate the ability to reduce on-pad processing time by 50 percent compared to the standard Falcon 1 launcher.

### Falcon 5 - Space Exploration Technologies Corporation

**Vehicle:** Falcon 5
**Developer:** Space Exploration Technologies Corporation
**First Launch:** late 2007
**Number of Stages:** 2
**Payload:** Up to 4,100 kg (9,000 lbs.) to LEO, 1,050 kg (2,315 lbs.) to GTO
**Possible Launch Sites:** Kwajalein Atoll, VAFB
**Targeted Markets:** Launch of medium-sized satellites, ISS resupply

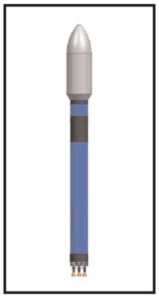

Falcon 5

The Falcon 5 vehicle is based on much of the same technology developed for Falcon 1. The larger Falcon 5 uses five SpaceX-developed Merlin engines in the first stage with an engine-out capability to enhance reliability. The second stage will use one Merlin engine, instead of two Kestrel engines as previously planned. Both stages are designed to be recovered and reused, if feasible. The Falcon 5 will be able to place up to 4,100 kilograms (9,000 pounds) into LEO and 1,050 kilograms (2,315 pounds) into GTO at a price of $18 million a launch. SpaceX has delayed introduction of the Falcon 5, previously planned for mid-2006, in order to focus on the development of the larger Falcon 9 version. The company now plans to make the Falcon 5 available to customers by late 2007.

### Falcon 9 - Space Exploration Technologies Corporation

**Vehicle:** Falcon 9
**Developer:** Space Exploration Technologies Corporation
**First Launch:** 2nd quarter 2007
**Number of Stages:** 2
**Payload:** Up to 24,750 kg (54,600 lbs.) to LEO, 9,650 kg (21,300 lbs.) to GTO
**Possible Launch Sites:** Kwajalein Atoll, VAFB
**Targeted Market:** Launch of large satellites

The Falcon 9, announced by SpaceX in September 2005, is the company's newest and largest launch vehicle. The Falcon 9 is similar to the Falcon 5, but features nine Merlin engines in its first stage. The medium version of the Falcon 9 can place up to 9,300 kilograms (20,500 pounds) into

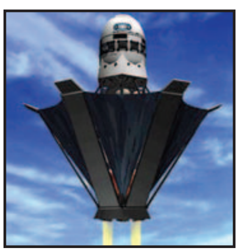

Falcon 9

LEO and 3,400 kilograms (7,500 pounds) into GTO. A "heavy" version, analogous to the Delta 4 Heavy, features two strap-on boosters similar to the Falcon 9 first stage with up to nine Merlin engines each. This version can carry up to 24,750 kilograms (54,600 pounds) to LEO and 9,650 kilograms (21,300 pounds) to GTO. Launch costs for the Falcon 9 range from $27 million for the medium version to $78 million for the heavy. Like the Falcon 5, both stages are intended to be recovered and reused, although the ability to reuse the stages is not factored into the current launch cost.

SpaceX has signed up an unspecified U.S. Government customer for the first Falcon 9 launch, scheduled for the second quarter of 2007. SpaceX will also launch a commercial payload for Bigelow Aerospace in the first quarter of 2008.[20]

### Michelle-B - TGV Rockets, Inc.

**Vehicle:** Michelle-B
**Developer:** TGV Rockets
**First Launch:** 2007
**Number of Stages:** 1
**Payload:** 1000 kg (2,200 lbs.) payload to 100 km
**Possible Launch Site:** White Sands
**Targeted Markets:** Remote sensing, microgravity science


Michelle-B

TGV Rockets, Inc. (TGV), is developing Michelle-B, a fully reusable, piloted suborbital vehicle designed to carry up to 1,000 kilograms (2,205 pounds) to an altitude of 100 kilometers (62 miles). This vehicle uses a vertical take-off and landing design, with a drag shield to assist in deceleration during landing. Michelle-B will provide up to 200 seconds of microgravity, while not exceeding 4.5 g during any phase of flight. Six pressure-fed LOX/kerosene engines for use on both ascent and landing power the vehicle. TGV's design is intended to enable high reusability, require minimal ground support, and allow the vehicle to return to flight within a few hours of landing. Flight testing of the Michelle-B is slated to begin in 2007.

### Xerus - XCOR Aerospace

**Vehicle:** Xerus
**Developer:** XCOR Aerospace
**First Launch:** TBD
**Number of Stages:** 1
**Payload:** 10 kg (22 lbs.) to LEO
**Possible Launch Site:** White Sands
**Targeted Markets:** Suborbital space tourism, nanosatellite launch


Xerus

In April 2004, XCOR Aerospace received a license from FAA/AST to perform flights from Mojave Airport in Mojave, California. These flights of the Sphinx demonstration vehicle are designed to fly within the Earth's atmosphere. For suborbital flight, XCOR is developing Xerus to conduct a variety of suborbital missions including microgravity research, suborbital tourism, and even the launch of very small satellites into orbit. Xerus is expected to have the ability to launch a 10-kilogram (22-pound) payload to LEO. XCOR is not currently disclosing its schedule or certain design details of the Xerus, except that it will take-off and land from a conventional runway without a booster stage or carrier vehicle. Xerus will be powered by XCOR's own liquid rocket engines.

## Government RLV Development Efforts

Throughout the 1980s and 1990s, both NASA and DoD conducted several joint and independent programs to produce experimental RLVs. These vehicles were intended to improve reliability, minimize operating costs, and demonstrate "aircraft-like" operations. None of these concepts, however, resulted in a fully operational vehicle.

In 2002, both NASA and the military reevaluated their RLV efforts. NASA implemented a revised Integrated Space Transportation Plan (ISTP) to better coordinate its space transportation efforts with its ISS, science, and research needs. The revised ISTP continued to support the Space Shuttle with a Service Life Extension Program (SLEP), and it restructured the Space Launch Initiative (SLI) to accommodate the development initially of an ISS CRV (crew rescue vehicle), and then the development of a CTV (crew transfer vehicle) called the Orbital Space Plane (OSP). The restructured SLI also had a component called the Next Generation Launch Technology (NGLT) to continue development of next generation and subsequent generations of launch vehicle technology.

On January 14, 2004, President George W. Bush announced a new vision to retire the Space Shuttle and develop a new vehicle capable of carrying astronauts to the ISS and explore space beyond LEO. After the announcement of the new Vision for Space Exploration in January 2004, NASA shut down both the OSP and NGLT programs as it shifted resources to Project Constellation, an effort to develop a new Crew Exploration Vehicle (CEV) and related mission architectures. The SLEP is now focused on near-term Shuttle upgrades given NASA's plan to retire the Space Shuttle fleet in 2010.

### Space Shuttle

**Vehicle:** Discovery, Atlantis, and Endeavour

**Developer:** Rockwell International (now Boeing). Fleet is managed, operated, and maintained on the ground by United Space Alliance, a joint venture between Boeing and Lockheed Martin.

**First Launch:** April 12, 1981

**Number of Stages:** 1.5

**Payload Performance:** 24,900 kg (54,890 lbs.) to LEO

**Launch Site:** Kennedy Space Center

**Markets Served:** Non-commercial payloads, ISS access

Consisting of an expendable external tank, two reusable solid rocket boosters, and a reusable Orbiter, NASA's STS (Space Transportation System), commonly referred to as the Space Shuttle, has conducted 114 launches from its introduction in 1981 through the return to flight of the Shuttle fleet in 2005.

The three remaining orbiters—Discovery, Atlantis, and Endeavour—were grounded after the Columbia accident. The fleet returned to flight with the successful launch of Discovery on mission STS-114 on July 26, 2005. However, problems with the loss of foam on the Shuttle's external tank during launch led NASA to delay future launches until the issue is resolved. NASA anticipates resuming Shuttle flights in the spring of 2006.

Space Shuttle

The Space Shuttle is the only means available today for completing assembly of the ISS. Intending to use the Shuttle until 2010, NASA is committed to investing in the Space Shuttle fleet to maintain safety and reliability and extend orbiter service life until its responsibilities constructing the ISS are complete. NASA's SLEP will support and maintain the Shuttles and associated infrastructure through the remainder of the Shuttle program. NASA will consider factors including safety, reliability, supportability, performance, and cost reduction in prioritizing improvement projects.

The Space Shuttle's day-to-day operations have been managed by United Space Alliance, a Boeing-Lockheed Martin joint venture, since 1996. NASA exercised two extension options to the contract and United Space Alliance is now supported through the end of fiscal year 2006. NASA is working on developing a new operations contract for fiscal year 2007 through the end of the Shuttle program.

### Affordable Responsive Spacelift

The Air Force is investigating the development of a partially-reusable launch system under the Affordable Responsive Spacelift (ARES) program. As currently envisioned, ARES would incorporate a reusable, winged fly-back lower stage and an expendable upper stage. An Analysis of Alternatives study by The Aerospace Corporation in early 2005 found that this concept offered a fast turnaround time (24-48 hours) at a lower cost than purely expendable or reusable systems. The USAF is beginning early-phase concept studies, including development of a subscale demonstrator that could launch small payloads into orbit. Current plans call for the first flight of this demonstrator around 2010, with a full-scale version, capable of placing up to 6,800 kilograms (15,000 pounds) into LEO, entering service by 2018.[21]

# Reentry Vehicles and In-Space Technology

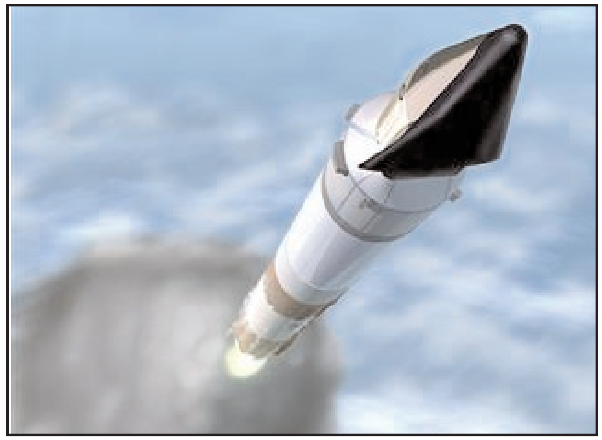
Under the Vision for Space Exploration, NASA has committed to both manned exploration of the Moon and Mars and a constant presence on the ISS. Thus, the earlier than expected retirement of the Shuttle in 2010, and reductions in its projected use until then, have accelerated the process of NASA selecting a Crew Exploration Vehicle (CEV) and a spacecraft to resupply and possibly launch additional sections of the ISS. A variety of vehicles are under development in order to fulfill both of these goals.

## CEV Competition

On June 13, 2005, NASA narrowed the competition to build the CEV by reducing the number of teams from eight to two: Lockheed Martin and a Northrop Grumman-Boeing joint venture.[22] Each team was awarded a $28 million contract to develop a complete design for the CEV and its Shuttle-derived launch vehicle. NASA Administrator Griffin plans to select one team in the Spring of 2006, so as to have the CEV ready for missions to the ISS no later than 2012. The CEV selection process was expedited to reduce development costs and shorten the window without a crewed vehicle. The Columbia accident investigation concluded that a capsule design, with a separate escape system, is most favorable for crew safety.

### Lockheed Martin

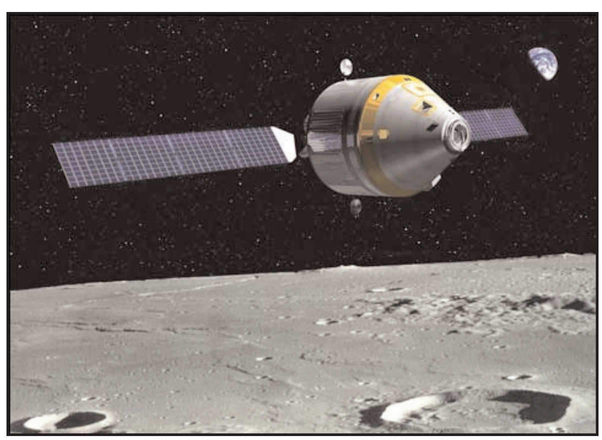
The CEV design prepared by Lockheed Martin resembles its proposal for the Orbital Space Plane (OSP) program, which was cancelled following the Columbia accident. The craft is designed to include a Crew Module with living space for four crew, and a rescue module with room for six. The craft will need additional modules for Moon and Mars missions. The Lockheed team includes Orbital Sciences, EADS Space Transportation, United Space Alliance, Honeywell, Wyle Laboratories, and Hamilton Sundstrand.



Lockheed Martin CEV

### Northrop Grumman-Boeing

The Northrop Grumman-Boeing team released their CEV proposal on October 12, 2005. Their modular, capsule-based approach recalls the earlier Apollo missions, but also promises evolutionary advantages. The crew capacity increases from Apollo's three to six, and use of lighter composite materials decreases the overall weight of the craft while increasing its total volume. The craft, intended to be further developed for lunar missions, has the capacity to operate on its own for up to six months in lunar orbit. The Northrop-Boeing team includes support from Alenia Spazio, risk management engineers ARES, Draper Laboratory, and United Space Alliance. The Northrop-Grumman team also claims that their CEV can operate for unmanned resupply missions to the ISS.



Northrop Grumman-Boeing CEV

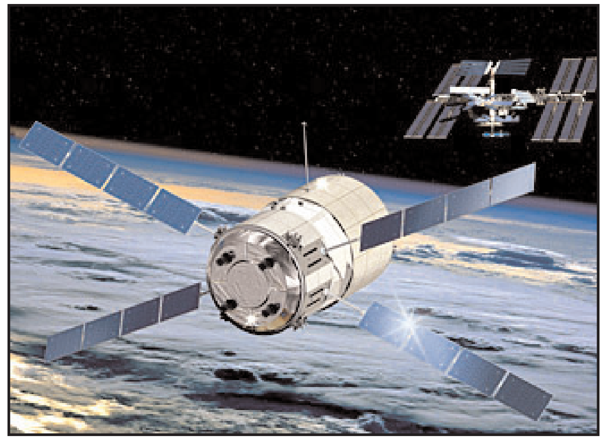
## ISS Resupply and Construction

The ISS continually needs to refresh its supplies, and still has some sections remaining for assembly. The declines in Shuttle flight forecasts, coupled with its early retirement, have prompted the development of other vehicles. Currently, the Russian Soyuz and Progress spacecraft are available to transport both crew and supplies. Other international vehicles in the works include the European Automated Transfer Vehicle and the Japanese H-2 Transfer Vehicle.

NASA would like to supplement this capacity with an American provider. NASA's Exploration Systems Mission Directorate issued a draft request for proposals in December 2005 to secure commercially provided cargo and crew resupply of the International Space Station. The Commercial Orbital Transportation Services (COTS) program, as currently planned, has two phases. First, vehicles capable of cargo transportation will be developed from May 2006 to somewhere within the 2008-2010 timeframe. Cargo transport vehicles should be able to lift up to 5,000 kilograms (11,000 pounds) of external cargo or 7,500 kilograms (16,500 pounds) of internal cargo for two to eight flights a year. Once companies have demonstrated the ability to transport cargo to and from the station, the second phase will support the development of a crewed vehicle capable of carrying three passengers for two to four flights a year. Corporations that apply for COTS should have at least 50 percent U.S. ownership. Total funding for the program from 2006 to 2010 is anticipated to be $500 million. Potential commercial providers for ISS resupply include Lockheed Martin, Spacehab, and t/Space. Kistler Aerospace, discussed previously in the RLV section, may also be a contender. All of these companies have vehicles designed to perform ISS resupply, with station assembly as an ancillary function.

### Lockheed Martin

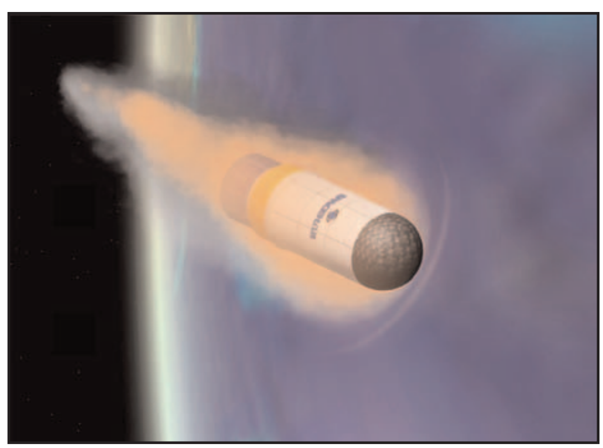
Lockheed Martin and EADS Space Transportation have joined forces to sell Europe's new Automated Transfer Vehicle (ATV) to NASA for ISS resupply. The first ATV is expected to launch in May 2007. The ATV weighs twenty metric tons (44,092 pounds), and is designed to haul three times the capacity of the Progress craft, up to nine metric tons (19,842 pounds). The ATV will be launched on the Ariane 5 rocket for European missions, and could potentially be launched by Lockheed's Atlas 5 if contracted by NASA.



Lockheed Martin-EADS ATV

### SPACEHAB

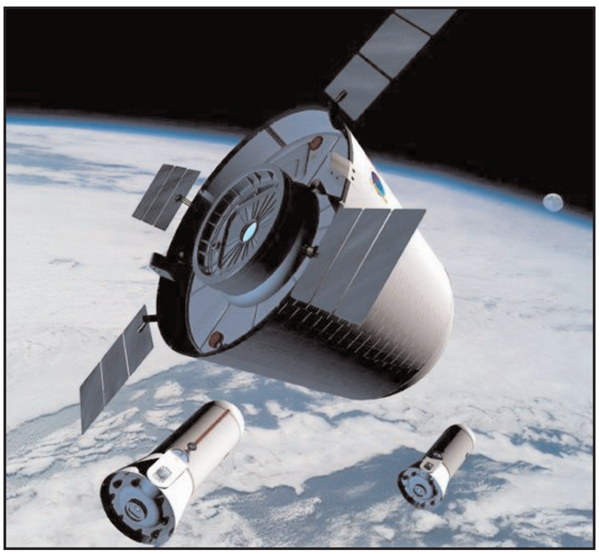
SPACEHAB has released its Apex design for both commercial and government markets. The Apex vehicles are available in three different configurations including one-, three-, and four-meter (3.3, 9.8, and 13.1 feet) approximate-diameter spacecraft. The smallest Apex can carry up to 300 kilograms (661 pounds) to LEO, with the larger two spacecraft carrying cargo of up to 1,300 and 6,000 kilograms (2,866 and 13,228 pounds), respectively. The largest Apex vehicle can be outfitted to carry crew. The first flight of the Apex is planned for 2007. The vehicle is designed to be launcher-neutral, with an open architecture capable of serving different markets.



SPACEHAB Apex

### Transformational Space Corporation

Transformational Space Corporation, also known as t/Space, forms one of the other teams that NASA considered for the CEV contract. While t/Space was not selected for the final round, it is still planning to build its Crew Transfer Vehicle (CXV) to carry up to four crew to either the ISS or LEO for under $20 million per flight. NASA Administrator Griffin announced on June 21, 2005 that “follower” contracts would also be awarded to companies not selected to be the final CEV producer. t/Space is aiming for the ISS resupply market, commercial prospects, and for potential selection on lunar missions. t/Space is allied with Ansari X Prize winner Scaled Composites. Its CXV would launch at high altitude from a large cargo carrier aircraft.



t/Space CXV

# Enabling Technologies

Several efforts are underway to develop enabling technologies for expendable and reusable launch vehicles. These efforts include government-sponsored and commercial research projects in the areas of avionics, air launch technologies, composite cryogenic fuel tanks and propulsion systems. Most of these development programs are focused on building new generation launch vehicle components that are substantially simpler, more flexible and reliable, and less costly than legacy technologies. Recent advances in propulsion systems covered here include the use of room-temperature propellants instead of cryogenics and pressure-fed engines instead of turbopumps. Hybrid rocket motors, liquid engines, propellant production, demonstrators, and hypersonic aircraft are described in this section.

## Launch Vehicle Avionics–SpaceDev, Inc. and Microcosm, Inc.

The search for decreased cycle time and cost in launch vehicle development programs, along with increased vehicle responsiveness, reliability, robustness and performance, has recently led NASA, DOD and vehicle manufacturers to consider new approaches to building flight avionics systems, particularly for small launchers.

During 2003-2004, Microcosm of El Segundo, California, developed under an AFRL contract a self-configuring, fault-tolerant, plug-and-play data network system for launch vehicle and satellite avionics. This system provides standardized data communications interfaces for components and is designed to enable hardware swapping with minimal impact to system command and control architecture and software. Devices and subsystems such as guidance and attitude control computers, MEMS gyros, telemetry systems, actuators and pressure, temperature, earth horizon, and sun sensors are connected using TCP/IP-based networking protocols. The avionics network is designed to be extendable to all other onboard command and control functions, providing a robust, flexible architecture that can accommodate a wide variety of hardware on the network without redesigning the system or updating the software.[23]

In May 2005 SpaceDev initiated development of standardized and miniaturized avionics for small launch vehicles under an AFRL SBIR contract. The goal is to substantially reduce the mass and cost of flight avionics while enhancing their scalability and reliability.[24]

## Air Launch t/Space and Scaled Composites

CXV and Booster Drop

t/Space and Scaled Composites successfully drop-tested dummy boosters over the Mojave Desert in 2005 using a new air launch method known as “Trapeze-Lanyard Air Drop”, or “t/LAD”. The t/LAD approach employs an innovative technique that causes a dropped booster to rotate towards vertical without requiring wings. This allows an aft-crossing trajectory in which the rocket crosses behind the carrier aircraft, greatly enhancing safety.

The innovation developed by t/Space is a new mechanism that holds on to the nose of the booster for about a half-second after the center of the rocket is released. This slight tug on the nose starts the booster rotating as it drops. A small parachute on the rocket’s nozzle ensures the rotation happens slowly. This approach provides improved simplicity, safety, cost, and reliability of launching people into LEO.[25]

Previous air-launched rockets such as the X-15, Pegasus and SpaceShipOne crossed in front of the carrier aircraft using wings to turn themselves from horizontal flight to the vertical position needed to achieve orbit. In addition to greatly enhancing safety, eliminating the weight of wings increases the payload the rocket can take to orbit.

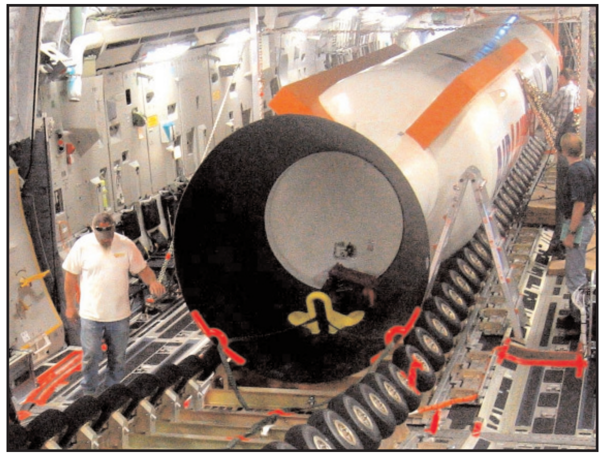
## Air Launch Method–AirLaunch LLC

In September 2005, AirLaunch LLC demonstrated the safe release of a dummy booster from an Air Force C-17A cargo plane. The C-17A flew to an altitude of 1,846 meters (6,000 feet) with the AirLaunch QuickReach booster inside the cargo bay resting on a pallet of upturned rubber wheels. As the aircraft turned nose-up by six degrees, gravity pulled the test article across the upturned tires and out the aft cargo door. The test demonstrated the QuickReach release technology, including proof that the booster's nose does not hit the C-17A roof as it leaves the aircraft.

The AirLaunch approach improves upon previous air-release methods such as the 1974 Minuteman missile air launch demo, which rested the booster on a pallet that then deployed parachutes to drag the pallet out of the cargo bay. The new AirLaunch method relies on gravity, not parachutes that can fail, and only the booster leaves the carrier aircraft—no pallets fall into the ocean or on to land. AirLaunch built a mock QuickReach booster for this drop as part of the DARPA/USAF FALCON program. It utilized a 20.2-meter (65.8-foot) long test article filled with water to bring its weight to about two-thirds the weight of an actual booster. The C-17A released the test article at 340 km/h (184 knots) air speed from 1,877 meters (6,100 feet) with future tests planned at the operational release altitude of 10,154 meters (33,000 feet).

The AirLaunch LLC design achieves responsiveness by carrying the booster to altitude inside the cargo bay of an unmodified C-17A or other large cargo aircraft. This avoids delays due to local weather—the carrier aircraft can fly to clear skies for the release—and it eliminates the need to coordinate with the schedules of the other users of the Nation's Western and Eastern launch ranges.

Major portions of the QuickReach air drop system were fabricated and assembled by Space Vector Corp. of Chatsworth, California. Universal Space Lines LLC of Newport Beach, California, provides avionics for QuickReach and Scaled Composites LLC of Mojave supplied specialized test equipment for the drop. The test was conducted at the Air Force Flight Test Center (AFFTC) and China Lake Naval Air Warfare Center (NAWC).



C-17A Dummy Booster Air Drop

AirLaunch LLC has now completed an $11.3-million contract under the FALCON program Phase IIA. If selected to move forward, the project would lead to a test flight to orbit in early 2008. The operational QuickReach booster is designed to put a 455 kilogram (1,000 pound) satellite into LEO.[26]

## Cryogenic Composite Tanks–Northrop Grumman and XCOR Aerospace

The use of composite materials to manufacture large, cryogenic fuel tanks is a critical enabler for reusable launch vehicles and future lunar and Mars exploration missions. These tanks, which are currently made from aluminum, carry liquid hydrogen, an essential but highly volatile fuel used in many rocket combustion processes. Identifying a suitable alternative to aluminum can be difficult, however, because liquid hydrogen must be stored and used at -253 degrees Celsius (-423 degrees Fahrenheit), a temperature at which most materials become quite brittle. The fuel also has an extremely fine molecular structure, which allows it to seep through the tiniest of holes.

The payoff for using composite tanks, however, is significant. They are typically 10 to 25 percent lighter than comparably sized aluminum tanks, which means they could provide increased payload-to-orbit lifting capabilities for new expendable or reusable launch vehicles. The use of composite tanks would also eliminate many current engineering costs associated with mating aluminum cryogenic fuel tanks to composite launch vehicle structures. Using composite materials for fuel tanks would effectively eliminate the need for specialized engineering solutions at critical joints between fuel tanks and the launch vehicle.

Subscale Composite Cryogenic Tank

Beginning in June 2001, under contract to NASA, Northrop Grumman performed design trade studies and a detailed analysis of composite materials and manufacturing techniques that could be used to develop reliable, permeation-resistant composite tanks. Based on these studies, Northrop designed a demonstration subscale composite fuel tank. Between April 2002 and May 2003, a Northrop/NASA team fabricated this tank using conventional, autoclave cured manufacturing processes. The subscale tank featured the use of a secondary barrier film between the inside face sheet of the sandwiched (laminate-honeycomb-laminate) tank wall and the honeycomb core to prevent liquid hydrogen from seeping into the tank walls and a perforated non-metallic honeycomb core design that helps purge on the launch pad or vent to space any liquid hydrogen that seeps past the barrier film, thereby ensuring crew safety.

Between November 2003 and September 2004, the Northrop/NASA team filled, applied internal and external loads, and drained the tank approximately 40 times to demonstrate its structural integrity at cryogenic temperatures, and its ability to be reused multiple times. The Northrop effort also developed and refined new manufacturing processes that will allow the firm to build large composite tanks without an autoclave, as well as design and engineering approaches supporting the creation of conformal fuel tanks suitable for use on single-stage-to-orbit vehicles.[27]

In April 2005, XCOR Aerospace of Mojave, California announced it had signed a $7-million contract with NASA to develop a composite cryogenic tank to hold liquid oxygen (LOX). This contract is part of NASA's Exploration Systems Research and Technology (ESR&T) program to develop key technologies for manned exploration of the Moon, Mars and beyond. The LOX tank will be designed to show dramatic weight savings by demonstrating the ability to serve as both an insulated tank and vehicle structure. The materials used in this tank retain their flexibility and toughness at cryogenic temperatures and are inherently non-flammable, an important safety feature for LOX tanks on future human spaceflight vehicles.[28]

The composite tank technology demonstrated to date and under development has potential applications not only as cryogenic fuel tanks for Earth-launched space vehicles, but also as on-orbit tanks for storage of cryogenic fuels such as liquid hydrogen or liquid oxygen. Such an orbiting "fuel depot" could be used to fuel space vehicles traveling from LEO to the moon or Mars.

## Liquid RCS Thruster–Orion Propulsion, Inc.

Oxygen/Methane RCS Thruster

Orion Propulsion Inc. (OPI) of Huntsville, Alabama, successfully completed the first series of tests on a 445-newton (100-pound-force) oxygen/methane RCS thruster in September 2005. Orion designed, manufactured, and tested this thruster, which accommodated an OPI-developed acoustic igniter and spark igniter. Over 40 firings of this gas-gas propulsion system were performed with a total of 90 seconds testing time.

This engine offers many advantages over existing RCS thrusters, including flexibility, reusability, affordability, and high performance. The engine can also burn methane that is mined during Mars In-Situ missions, or stored on long-term orbit missions. OPI has begun planning for testing the thruster with a space nozzle. The company expects to qualify the engine to burn a variety of easily stored propellants, including propane/nitrous oxide, ethane/nitrous oxide, and hydrogen/oxygen.

Orion and HMX Inc. plan to jointly develop a product line based on this flexible engine design. The first application will be the t/Space CXV human spaceflight vehicle for NASA. Orion performed the testing at its facility near Huntsville, Alabama.[29]

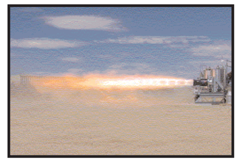
## Liquid Engines–Orbital Technologies Corporation

In November 2005, Orbital Technologies Corporation (ORBITEC) of Madison, Wisconsin, completed successful testing of a prototype rocket engine using methane fuel and oxygen oxidizer. Methane is currently of interest for NASA's Vision for Space Exploration and for future USAF launch vehicles. It requires smaller propellant tanks than hydrogen, has higher specific impulse than hydrocarbon fuels such as kerosene, and when used for exploration, methane and oxygen can be produced on Mars from planetary resources found there. NASA is interested in applying liquid methane/liquid oxygen propellants for Lunar and Mars landing and other transport vehicles. The USAF is interested in methane for future use in launch vehicles. ORBITEC believes this technology will enable the development of low-cost, reusable rocket engines for spaceplanes, suborbital and orbital launch vehicles, and orbital transfer stages for a variety of military and civil space missions.

The ORBITEC engine used ORBITEC's patented "vortex-cooled" combustion process to eliminate combustion chamber heating. ORBITEC conducted over 70 hot firings with the vortex-cooled methane engine to refine the design of the propellant injectors and combustion chamber. This program resulted in a design that provided very high performance of 98 percent of an ideal rocket with no significant chamber heating upstream of the exit nozzle. The chamber operated at a thrust of approximately 133 newtons (30 pounds-force) and a chamber pressure of 1.03 megapascals (150 pounds per square inch absolute). Similar testing with hydrogen in a larger chamber also demonstrated very low chamber heating at pressures of 3.45 megapascals (500 pounds per square inch absolute) and high performance.

ORBITEC has also conducted successful methane/oxygen ignition system developments and has applied them to its larger rocket engine testing. ORBITEC previously conducted successful engine firing tests of solid methane and solid methane-aluminum in cryogenic solid hybrid rocket engines with gaseous oxygen. This current research is being conducted with the support of a Phase 3 SBIR contract from the AFRL.[30]

## Liquid Engines–AirLaunch LLC



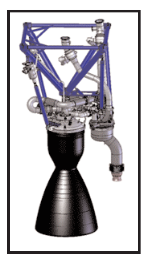
Liquid Oxygen/ Propane Engine

AirLaunch has completed flow calibration, ignition and initial short duration tests of a liquid oxygen and propane powered upper stage rocket engine that has application for future small spacecraft launchers. The tests were conducted from April to June 2005 at the Civilian Flight Test Center, Mojave Spaceport.

The engine employs an ablative chamber and nozzle, and is designed to produce 106,800 newtons (24,000 pounds force) force when operating in a vacuum with an extension nozzle. The extension is not installed for sea level tests.

Testing demonstrated that the engine is stable, can be ignited quickly after shutdown and is ready to move into the next phase of development. Work on this engine was conducted in support of the DARPA/USAF FALCON program.[31]

## Liquid Engines–Space Exploration Technologies Corporation



SpaceX Merlin Engine

SpaceX of El Segundo, California, completed development in early 2005 of two new liquid-propellant engines for use on its Falcon I launch vehicle. The first stage engine, known as Merlin 1A, is a high pressure 342,650-newton (77,000-pound-force) at sea level thrust engine that is turbo-pump fed with a gas generator cycle. The second stage engine, known as Kestrel, is a pressure-fed engine that produces 31,150 newtons (7,000 pounds-force) thrust (vacuum). Both engines use LOX/kerosene propellants. SpaceX began development on the Falcon V Merlin 1B upgrade engine (378,250 newtons/85,000 pounds-force at sea level) in 2005. The company expects to complete a Falcon V stage hold down firing with all M1B engines by the end of 2005. The next major engine development is Merlin 2, where SpaceX will aim for a significant increase in thrust and chamber pressure. Merlin 2 will serve as an exact scale version of the F-1 class (>6,675,000 newtons or 1.5 million pounds-force thrust) engine that SpaceX intends to start developing in a few years.[32]

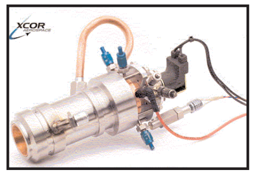
## Liquid Engines–XCOR Aerospace

XCOR Aerospace, located in Mojave, California, specializes in developing engines and propulsion systems for use on launch vehicles and spacecraft. The company has developed and extensively tested six liquid-propellant engines. XCOR's largest engine currently in active development, designated XR4K5, is an 8,000-newton (1,800-pound-force) engine that is pump-fed, LOX/kerosene regeneratively cooled with fuel. This engine may be used to power the prototype Xerus vehicle for initial flight testing, but XCOR has not yet decided on this approach.

The XR4A3 is a fully operational 1,780-newton (400-pound-force), pressure-fed, regeneratively cooled, liquid oxygen and alcohol engine. Four such engines have been built and, combined, have been run 558 times for over 6,434 seconds. These engines have also been flown on the EZ-Rocket, a modified Long-EZ aircraft fitted with two of the engines. The EZ-Rocket has completed 15 successful flight tests since July 2001, including two flights at the Experimental Aircraft Association's AirVenture 2002 air show in Oshkosh, Wisconsin, in July 2002.

XCOR has built four smaller engines. The XR3A2 700-newton (160-pound-force) engine was the first LOX/alcohol engine, accumulating 61 brief runs in the course of injector concept development, which led to later engines. The XCOR XR3B4 regeneratively cooled engine is capable of 220 newtons (50 pounds-force) thrust, using nitrous oxide and isopropyl alcohol as propellants. This engine has completed 216 runs with a cumulative burn time of more than 812 seconds. XCOR designed this engine for use as a maneuvering thruster on spacecraft. A 67-newton (15-pound-force) engine, designated XR2P1, using nitrous oxide and ethane as propellants, was initially built to test the design of proposed larger engines. With a cumulative burn time of 103 minutes, this engine has completed in excess of 1,189 runs. It continues to serve as a workhorse engine for a wide variety of experiments, crew training activities, and educational demonstrations. The XR2P1 has run on oxygen and nitrous oxide oxidizers, with propane, ethane, kerosene, turpentine, and a variety of alcohols.[33]

In April 2002, XCOR acquired selected intellectual property assets of the former Rotary Rocket Company. These assets included a 22,250-newton (5,000-pound-force) LOX/kerosene engine developed and tested by the company as well as hydrogen peroxide engine technology. XCOR has completed development of their fourth-generation igniter with integral valves and is now developing composite LOX tank technology with inherent materials compatibility and superior structural effectiveness. A piston pump suitable for use with LOX/kerosene, alcohol, or both, fuels is currently under development and will be merged with the XR4K5 engine.



Liquid Oxygen/ Methane Engine

In August 2005 XCOR successfully completed its first series of tests on the 3M9 223-newton (50-pound-force) thrust rocket engine fueled by methane and liquid oxygen. The engine tests consisted of 22 engine firings totaling 65 seconds. The longest engine firing was 7 seconds. This first series of tests were done with self-pressurizing propellants. Pressure-fed and pump-fed versions are also in development.

The advantages of a methane-fueled engine include long-term on-orbit storage, higher density than hydrogen engines, higher performance than kerosene engines, and the potential for using methane derived from the Martian atmosphere as a fuel source. Future generations of the 3M9 engine are intended for use as Reaction Control Systems (RCS) and satellite maneuvering systems. The engine tests took place at XCOR's facilities at Mojave Spaceport.[34]

## Liquid Engines–Microcosm, Inc.

Microcosm is developing a family of liquid-propellant rocket engines for its Scorpius series of ELVs and other users (see the ELV section for a description of Scorpius). The company has built a pressure-fed, ablatively cooled, 22,250-newton (5,000-pound-force) thrust engine using liquid oxygen and jet fuel as propellants. This engine was successfully tested on the company's SR-S and SRXM-1 sounding rockets launched in January 1999 and March 2001. The engine will also be used as the upper stage engine for the Sprite Mini-Lift orbital vehicle should that vehicle move into final development.

Low-cost, ablative composite rocket engine

In May 2005 Microcosm successfully completed a series of tests of an 89,000-newton (20,000-pound-force) low-cost ablative composite rocket engine for responsive launch vehicle applications. Several engines underwent a series of tests ranging from 1 second to 30 seconds in duration with multiple injectors, chambers, and operating pressures. The testing was the combined effort of Microcosm; Sierra Engineering of Carson City, Nevada, which designed the injector for the engine; and the AFRL facilities at Edwards Air Force Base where the tests were conducted. This engine will be used on the booster pods and sustainer stage of the Microcosm Eagle SLV included in the DARPA and USAF FALCON Small Launch Vehicle Program.[35]

In addition, a new 356,000-newton (80,000-pound-force) engine has started development under an AFRL SBIR Phase 1 contract. Both the 20,000-pound-force and 80,000 pound-force engines are follow-on developments to the successful 5,000-pound-force engines. All are ablative chamber, LOX/Jet A propellant engines designed for very low-cost, robust design margins, moderate chamber pressures, high reliability, and expendable applications.

## Liquid Engines–MB-XX–Pratt & Whitney Rocketdyne

MB-XX Engine

Rocketdyne Propulsion & Power, part of Pratt & Whitney's Space Propulsion division operating as Pratt & Whitney Rocketdyne (a wholly owned subsidiary of United Technologies Corporation), is developing new technologies and engines for space launch vehicles. In August 2005, United Technologies Corporation (UTC) acquired Rocketdyne Propulsion & Power from The Boeing Company. Rocketdyne is developing advanced health management systems, new materials, advanced processes, and new components that enable rocket engines to be safer and more reliable. These technologies are being demonstrated on development engines, such as the Integrated Powerhead Demonstrator engine with the USAF and NASA, and on the new MB-XX upper stage engine to verify their characteristics.

NASA refocused its 2003 efforts on the Vision for Space Exploration in 2004, halting work on the RS-84 to study and determine the type of vehicle and propulsion required to return the U.S. to the Moon and prepare to go to Mars. Rocketdyne is evaluating various propulsion options to meet the Vision for Space Exploration requirements and to enable significant improvements in current ELVs. Areas under consideration include the reliable SSME; the proven J-2S Saturn engines from the Apollo era; a derivative of the Delta 4 launch vehicle engine, the RS-68; RS-84 technology; and the MB-XX upper stage engine.[36]

The MB-XX is being demonstrated on funding from Boeing and Mitsubishi Heavy Industries for potential application to the Vision for Space Exploration launch vehicle or upgrades to today's EELVs. Rocketdyne completed PDR on the RS-84 rocket engine, which is the first reusable hydrocarbon staged combustion rocket engine. This engine is designed to produce 4,728,889 newtons (1,064,000 pounds-force) of thrust at sea level with a design life of 100 missions.

The MB-60 engine is the first member of the MB-XX family to begin development, and is targeted for use on the Delta 4 launch vehicle.[37] This multiple-restart engine is designed to produce 267,000 newtons (60,000 pounds-force) of thrust (vacuum), and a nominal specific impulse of 467 seconds.

## Aerospike Liquid Engine–Garvey Spacecraft Corporation

During 2005, GSC and California State University, Long Beach (CSULB) conducted several notable small launch vehicle R&D activities through their partnership in the California Launch Vehicle Education Initiative. Using a single-chamber, liquid-propellant, annular aerospike engine concept

Aerospike engine static fire test

developed by CSULB, the GSC/CSULB team validated the basic design and ignition sequence with a successful static fire test at the Reaction Research Society's Mojave Test Area (MTA) in June 2003. The team then mounted one of these 4,444-newton (1,000-pound-force) thrust LOX/ ethanol ablative engines onto their Prospector 2 vehicle and proceeded to conduct the first-ever powered liquid-propellant aerospike flight test at the MTA in September 2003. In response to several issues observed during that flight, modifications were made to the engine fabrication process. Another flight test with the Prospector 4 vehicle followed in December 2003. Performance was entirely nominal, resulting in complete recovery of the vehicle and key trajectory data.

These CALVEIN flight tests represent the first steps toward obtaining the critical empirical data needed to validate whether the predicted benefits of such aerospike engines versus those equipped with standard bell-shaped nozzles can be achieved. This goal had been one of the primary objectives of the X-33 program, which featured the XRS-2200 linear aerospike engine.

The CSULB students are now investigating a next-generation aerospike engine design, featuring a more traditional multi-chamber design. This design will enable the large expansion ratios required to fully evaluate engine performance throughout the entire flight regime of an orbital launch vehicle.

As part of an evaluation of fuels for the NLV that could provide greater performance than the ethanol used in the current CALVEIN research vehicles, the team has identified propylene as a promising candidate meriting further attention. Liquid oxygen and propylene have the potential to provide higher specific impulse than the traditional LOX/RP-1 propellant combination. Unlike another alternative hydrocarbon that has received extensive discussion (methane), propylene can achieve comparable densities to that of RP-1 when chilled to cryogenic temperatures. A widely available commodity because of its role as a feedstock in the plastics industry, propylene also has favorable characteristics with respect to toxicity and environmental hazards. Some of the potential concerns about propylene, most notably its potential for polymerization, are only relevant for turbopump-fed regenerative engines. Therefore, those concerns are not issues for the pressure-fed NLV stages that feature ablative and radiative engine chambers.

The GSC/CSULB conducted a series of static fire tests at the MTA to identify logistics and handling issues associated with propylene and to evaluate a preliminary engine design for the NLV second stage. Preliminary results confirm that the ignition sequence is more susceptible to a hard start than liquid oxygen and ethanol. For this initial phase of testing, the propylene has been at ambient temperatures. A round of follow-on testing will evaluate several different ignition sequences and engine performance with propylene at cryogenic conditions. Upon successful completion of that phase of research, the team plans to conduct a LOX and propylene flight test using a modified version of the Prospector-class vehicles.[38]

The next important milestone was achieved by the joint industry-academic team in December 2004 when they conducted their initial launch and recovery of a full-scale flight development unit for NLV. The Prospector 5 vehicle, and early version of the NLV first stage, was launched and then recovered by parachute.[39]

## Integrated Powerhead Demonstrator–NASA

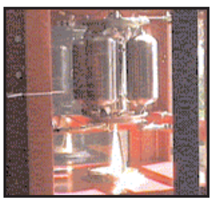
The Integrated Powerhead Demonstrator (IPD) is a joint venture between NASA and the Integrated High Payoff Rocket Propulsion Technologies program, managed for DoD by the AFRL at EAFB. This project is the first phase of a full-scale effort to develop a flight-rated, full-flow, hydrogen-fueled, staged combustion rocket engine in the 1.1-million-newton (250,000-pound-force) thrust class. The IPD will employ dual preburners that provide both oxygen-rich and hydrogen-rich staged combustion. Such combustion is expected to keep engines cool during flight, achieve high system efficiency, and reduce exhaust emissions.

Pratt & Whitney Rocketdyne is developing the liquid-hydrogen fuel turbopump and the demonstrator's oxygen pump, main injector, and main combustion chamber. Aerojet Corporation of Sacramento, California, designed and tested the

IPD test at NASA Stennis Space Center

oxidizer preburner, which initiates the combustion process with oxygen-rich steam. Aerojet also is responsible for development of the demonstrator engine's fuel preburner, designed to supply the fuel turbopump's turbine with hot, hydrogen-rich steam. Boeing-Rocketdyne will lead overall system integration once component-level development and testing are complete. The IPD underwent integrated testing at Stennis Space Center from late 2004 through September 2005, and in April 2005 NASA announced that it was successfully fired during an initial full-duration test.[40]

### Hybrid Rocket Motors–SpaceDev, Inc.



SpaceDev hybrid propulsion system

In 1998, SpaceDev, Inc., of Poway, California, acquired exclusive rights to the intellectual property of the American Rocket Company, which had developed hybrid rocket motor systems in the 1980s. SpaceDev is currently developing a series of small hybrid motors, using HTPB rubber or polymethyl methacrylate (Plexiglas) as solid fuel and storable nitrous oxide as a gaseous oxidizer. SpaceDev completed tests in August 2001 of a small hybrid rocket motor that is designed for use in the company's Maneuver and Transfer Vehicle, an upper stage that can move small spacecraft, such as secondary payloads on larger launch vehicles, from GTO, LEO or GEO. In May 2002, the AFRL awarded SpaceDev a contract to develop a hybrid propulsion module to deploy small payloads from the Space Shuttle. In September 2003, Scaled Composites announced that it had selected SpaceDev for propulsion support for its SpaceShipOne project. In a series of flights in late 2004, SpaceDev's hybrid rocket motor powered SpaceShipOne to suborbital space twice in two weeks, thus propelling it to win the Ansari X Prize. In October 2004, SpaceDev was awarded about $1.5 million to proceed with Phase 2 of its SBIR contract from the AFRL to continue its hybrid rocket motor-based small launch vehicle project. The company is presently in the fabrication phase of the first test article for this upper-stage hybrid propulsion system.[41]

### Hybrid Propulsion Systems–Lockheed Martin-Michoud

Hybrid motors of the 1.1-million-newton (250,000-pound-force) thrust class are being studied for possible use on current and future launch vehicles. Funding for the hybrid team came from the DoD Technology Reinvestment Program, NASA monetary and in-kind support, and contributions of industry team members.[42]

In November 2003, Lockheed Martin-Michoud Operations was awarded a six-month study contract from DARPA as part of the USAF FALCON program to assess hybrid propulsion applications for a responsive small launch vehicle. This study concluded in May 2004. In September 2004, FALCON competitors began a 10-month design phase to be followed by a down-select to possibly two competitors, and a winning design to be selected in 2007. Lockheed Martin-Michoud's all-hybrid two-stage vehicle will deliver a payload up to 455 kilograms (1,000 pounds) to LEO and, if selected, will establish hybrid propulsion as a viable space launch booster technology. The core booster stage will generate approximately 1.4 million newtons (320,000 pounds-force) of thrust and the second stage approximately 133,333 newtons (30,000 pounds-force) of thrust to meet mission objectives using a HTPB and LOX motor.

Staged combustion hybrid technologies have been demonstrated on the ground by Lockheed Martin-Michoud Operations in over 600 ground tests of small and large diameter motor firings at the NASA Stennis Space Center and MSFC. Lockheed Martin-Michoud has six patents and more than $10 million of internal R&D invested to date.

### Hyper-X Series Vehicles–NASA

X-43A/Hyper X

On March 27, 2004, four decades of supersonic-combustion ramjet (scramjet) propulsion research culminated in a successful flight of the X-43A hypersonic technology demonstrator, the first time a scramjet-powered aircraft had flown freely. On November 16, 2004, an identical scramjet-powered X-43A repeated this feat.

Chemical rocket systems combust a fuel and oxygen mixture to produce thrust. By carrying everything needed for combustion, these engines can operate in the vacuum of space. Conventional turbojets also burn fuel and an oxidizer, but the oxidizer comes from the atmosphere. Without the need for oxidizer tankage, these engines are lighter than rockets but cannot operate in rarified air or a vacuum. For vehicles intended to conduct powered flight from the Earth's surface up to space and back, such as RLVs, an engine capable of operating throughout changing atmospheric conditions is the ideal propulsion solution.

NASA's Langley Research Center in Hampton, Virginia, has managed the Hyper-X program to develop air-breathing rocket technology since 1997. The vehicle is the result of collaboration between ATK-GASL, which built the airframe and engine, and Boeing Phantom Works, which constructed the thermal protection system.

Other technology efforts have flown scramjet engines, but those engines were permanently affixed to the carrier rockets. Supersonic combustion ramjets, or scramjets, are air-breathing engines with no moving parts, similar to ramjets. Unlike ramjets, however, scramjets only operate at supersonic speeds. The gaseous hydrogen burning engines of the X-43A were enclosed in a 3.7 meter (12 feet) long airframe and propelled the vehicle at velocities of approximately Mach 7 and Mach 10. The 3.7-meter (12-foot) long vehicle has accelerated to Mach 7 (for the first flight) or Mach 10 (for the final flight) by the first stage of an Orbital Sciences Corporation Pegasus XL launch vehicle. Then, the X-43A separates from the booster for independent flight at high speed.43 The whole stack was dropped from NASA's B-52B carrier aircraft.

During a successful test flight conducted in 2004, the NASA B-52 aircraft released the vehicle at an altitude of 12.2 kilometers (7.6 miles) to reduce the aerodynamic loads on the control surfaces of the booster. The X-43A was boosted to a test flight altitude of 29 kilometers (18 miles) by a modified Pegasus XL rocket. Then, it separated for a 10-second period of scramjet-powered flight. The flight achieved a speed of Mach 6.83.

The Hyper-X program not only proved the maturity of scramjet technology but also recorded valuable environmental data on hypersonic flight. During the second and final X-43A flight in November 2004, a speed of Mach 9.8 was reached. The resulting vehicle skin temperatures of 1,982 degrees Celsius (3,600 degrees Fahrenheit) were far above the melting point of conventional aircraft structures and required a thermal protection system. Because existing wind tunnels are incapable of generating Mach 10 airflow, the final X-43A flight provided a one-of-a-kind opportunity for research into this flight regime. The X-43A proved that the United States can produce air-breathing vehicles capable of sustained actively controlled flight at hypersonic speeds.

In October 2005, Alliant Techsystems received a five-year, $15 million contract from NASA's Aeronautics Research Mission Directorate to conduct hypersonic aero-propulsion research, test, and evaluation in specially designed wind-tunnels that replicate the atmospheric conditions aircraft experience if traveling at speeds up to Mach 20.

Hypersonic vehicles promise to enable future RLV systems, such as two-stage-to-orbit systems. In addition to serving as RLV propulsion, hypersonic engines may enable production of hypersonic munitions for the military.

## Propellant Production–Andrews Space, Inc.

Gryphon with orbiter

Andrews Space, Inc., of Seattle, Washington, has developed an In-flight Propellant Collection System, the "Alchemist" Air Collection and Enrichment System (ACES), which generates liquid oxygen (LOX) through the separation of atmospheric air. ACES takes high-pressure air from turbofan jet engines flying at subsonic speeds and liquefies it by passing the air through a series of heat exchangers cooled by liquid nitrogen, liquid hydrogen, or both. Then, using a fractional distillation process, liquid oxygen is separated into its constituent parts and stored in propellant tanks for use by liquid hydrogen and LOX rocket engines.

Alchemist™ ACES allows horizontal take-off and landing launch vehicles to leave the ground without oxidizer, dramatically reducing their take-off weight, increasing payload capability, or both.

Since it allows vehicles to take off without LOX on board-minimizing vehicle takeoff weight-the ACES technology is critical for Horizontal Takeoff, Horizontal Landing (HTHL) architectures to meet NASA's next-generation safety, economic, and operational goals with existing air-breathing and rocket propulsion systems. Because LOX represents a significant fraction of take-off weight, this approach allows a dramatically smaller launch vehicle for a given payload size.

The company has proposed Alchemist™ ACES in conjunction with its two-stage-to-orbit RLV design—known as Gryphon–as well as for use in other horizontal take-off launch vehicles. Andrews Space carried out initial studies of the Alchemist™ ACES technology using internal funds, then under a NASA SBIR contract. Detailed feasibility studies and risk analyses were carried out under a NASA SLI contract.

Critical components for the ACES system are presently in prototype hardware development at Andrews under a DARPA seedling contract. Future work involving design, fabrication, and test of a subscale all-up ACES system on board a flight vehicle is now in the planning stage. ACES was first demonstrated in the 1960's for the USAF Aerospaceplane program.[44]

# Spaceports

Launch and reentry sites—often referred to as "spaceports"—are the nation's gateways to and from space. Although individual capabilities vary, these facilities may house launch pads and runways as well as the infrastructure, equipment, and fuels needed to process launch vehicles and their payloads before launch. The first such facilities in the United States emerged in the 1940s when the federal government began to build and operate space launch ranges and bases to meet a variety of national needs.

While U.S. military and civil government agencies were the original and still are the primary users and operators of these facilities, commercial payload customers have become frequent users of federal spaceports as well. Federal facilities are not the only portals to and from space. Indeed, the commercial dimension of U.S. space activity is evident not only in the numbers of commercially-procured launches but also in the presence of non-federal launch sites supplementing federally operated sites.

Since 1996, FAA/AST has licensed the operations of five non-federal launch sites. These spaceports have served both commercial and government payload owners. To date about $165 million has been invested into non-federal spaceports across the nation. The activity is primarily funded by the individual states with private sponsorship and some federal government support. An average of $2.8 million is spent yearly operating the established, licensed spaceports and $270,000 towards the development of each proposed spaceport.[45]

Table 3 shows which states have non-federal, federal, and proposed spaceports. Non-federal and federal spaceports capable of supporting launch and landing activities that currently exist in the United States are also described. A subsection detailing state and private proposals for future spaceports with launch and landing capabilities is included.

Table 3: Spaceport Summary by State

| State | Non-federal | Federal | Proposed |
|---|---|---|---|
| Alabama | | | ☑ |
| Alaska | ☑ | | |
| California | ☑ | ☑ | |
| Florida | ☑ | ☑ | |
| Kwajalein | | ☑ | |
| New Mexico | | ☑ | ☑ |
| Oklahoma | | | ☑ |
| Texas | | | ☑ |
| Virginia | ☑ | ☑ | |
| Washington | | | ☑ |
| Wisconsin | | | ☑ |

## Non-Federal Spaceports with FAA/AST Licenses

While the majority of licensed launch activity still occurs at U.S. federal ranges, much future launch and landing activity may originate from private or state-operated spaceports. For a non-federal entity to operate a launch or landing site in the United States, it is necessary to obtain a license from the federal government through FAA/AST. To date, FAA/AST has licensed the operations of five non-federal launch sites, all of which are described in this subsection. Three of these are co-located with federal launch sites, including the California Spaceport at VAFB, Florida Space Authority (FSA) at Cape Canaveral, Florida, and MARS (originally the Virginia Space Flight Center) at Wallops Flight Facility (WFF), Virginia. The first orbital launch from an FAA/AST-licensed site occurred on January 6, 1998, when a Lockheed Martin Athena 2, carrying NASA's Lunar Prospector spacecraft, successfully lifted off from FSA's LC-46. Table 4 summarizes the characteristics of FAA/AST licensed spaceports.

Table 4: Licensed Non-federal Spaceports: Infrastructure and Status

| Spaceport | Location | Owner/Operator | Launch Infrastructure | Development Status |
|---|---|---|---|---|
| California Spaceport | Vandenberg AFB, California | Spaceport Systems International | Existing launch pads, runways, payload processing facilities, telemetry and tracking equipment. | Work completed in 2004 to build a rolling access gantry to support Minuteman and future Peacekeeper space booster derivatives. New SLC-8 gantry installed in 2005. |
| Kodiak Launch Complex | Kodiak Island, Alaska | Alaska Aerospace Development Corporation | Launch control center, payload processing facility, and integration and processing facility. Orbital and suborbital launch pads. Maintenance and storage facility. Limited range support infrastructure (uses mobile equipment). | AADC purchased in 2005 two Mobile Telemetry Systems to augment primary range safety system. Second suborbital launch pad, motor storage facility and improved fiber-optic connectivity to continental U.S. are planned. Paving of improved road scheduled for completion in 2007. |
| Spaceport Operated by FSA | Cape Canaveral, Florida | Florida Space Authority | One launch complex, including a pad and a remote control center; a small payload preparation facility; and an RLV support facility. | Has invested over $500 million to upgrade launch sites, build an RLV support complex adjacent to the Shuttle Landing Facility, develop a new space operations support complex, and build a state-of-the-art research facility at Kennedy Space Center. |
| Mid-Atlantic Regional Spaceport | Wallops Island, Virginia | Virginia Commercial Space Flight Authority | Two orbital launch pads, payload processing and integration facility vehicle storage and assembly buildings, on-site and downrange telemetry and tracking, and payload recovery capability. | Significant upgrades to Pad 0B were completed in 2005 to make it fully compatible with liquid as well as solid fueled launch vehicles. The Movable Service Structure on Pad 0B was validated in 2005 to support Minuteman and Peacekeeper-derived launch vehicles. Phase I development of new Multipurpose Processing Facility (MPF) and Liquid Fueling Facility (LFF) were completed in 2005. |
| Mojave Airport | Mojave, California | East Kern Airport District | Air control tower, 3 runways, rotor test stand, engineering facilities, high bay building. Easy access to restricted airspace. Runway extended to 12,500 feet. | FAA/AST approved site license. Scaled Composites' SS1 has launched from this site for the Ansari X Prize competition. |

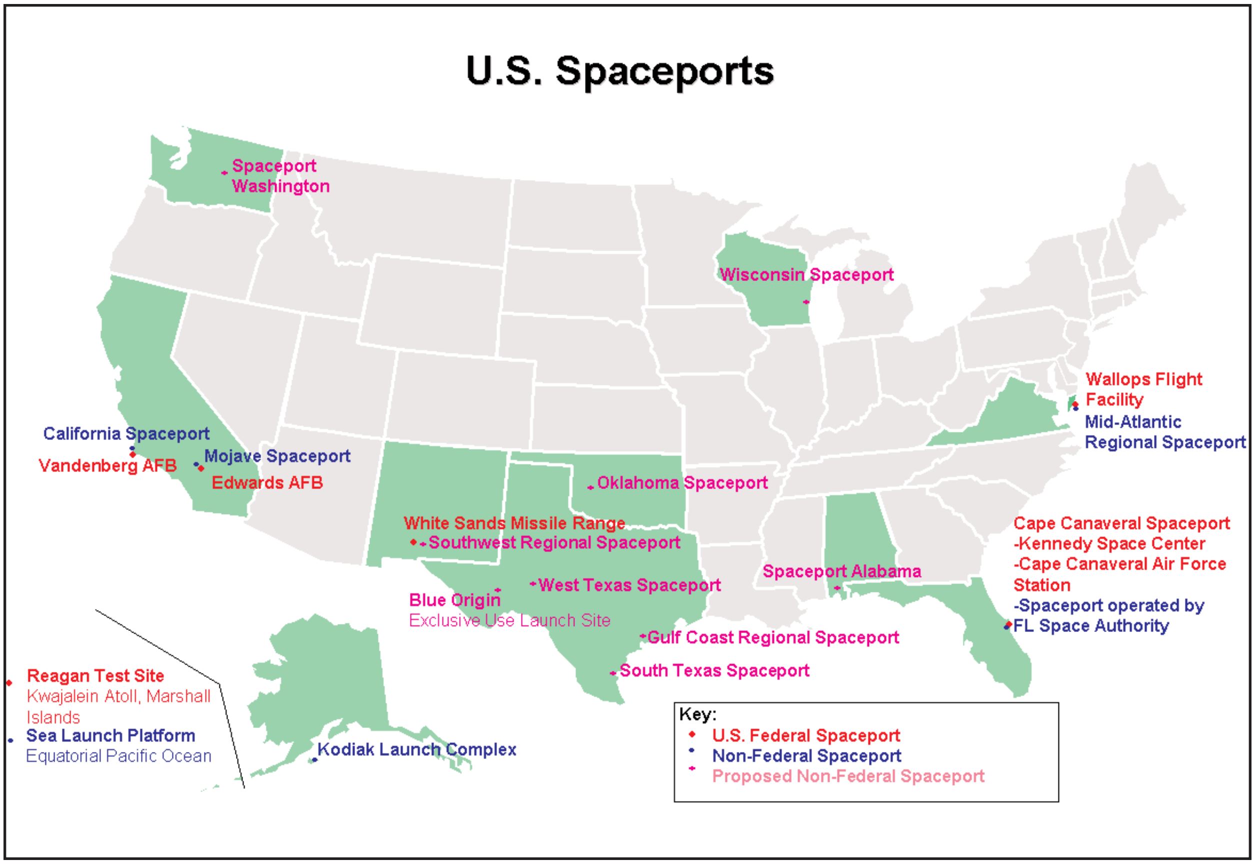
## California Spaceport

On September 19, 1996, the California Spaceport became the first commercial spaceport licensed by FAA/AST. In June 2001, FAA/AST renewed the spaceport's license for another five years. The California Spaceport offers commercial launch and payload processing services and is operated and managed by Spaceport Systems International (SSI), a limited partnership of ITT Federal Service Corporation. Co-located at VAFB on the central California coast, SSI signed a 25-year lease in 1995 for 0.44 square kilometers (0.17 square miles) of land. Located at latitude 34º North, the California Spaceport can support a variety of mission profiles to low-polar-orbit inclinations, with possible launch azimuths ranging from 220 degrees to 165 degrees.

Initial construction of the California Spaceport's Commercial Launch Facility began in 1995 and was completed in 1999. The design concept is based on a "building block" approach. Power and communications cabling was routed underground to provide a launch pad with the flexibility to accommodate a

California Spaceport

variety of launch systems. Additional work was completed in 2004 to build a rolling access gantry to support Minuteman and future Peacekeeper space booster derivatives. Although the facility is configured to support solid-propellant vehicles, plans are in place to equip the launch facility with support systems/commodities required by liquid-fueled boosters. The current SLC-8 configuration consists of the following infrastructure: pad deck, support




equipment building, launch equipment vault, launch duct, launch stand, access tower, communications equipment, and Integrated Processing Facility (IPF) launch control room as well as the required Western Range interfaces needed to support a launch. The final SLC-8 configuration awaits future customer requirements. When fully developed, the SLC-8 Launch Facility will accommodate a wide variety of launch vehicles, including the Minuteman-based Minotaur and Castor 120-based vehicles, such as Athena and Taurus.

Originally, the focus of the California Spaceport's payload processing services was on the refurbishment of the Shuttle Payload Preparation Room. Located near SLC-6, this large clean room facility was originally designed to process three Space Shuttle payloads simultaneously. It is now leased and operated by the California Spaceport as the Integrated Processing Facility (IPF). Today, payload-processing activities occur on a regular basis. The IPF has supported booster processing, upper stage processing, encapsulation, and commercial, civil, and USAF satellite processing and their associated administrative activities. The IPF can handle all customer payload processing needs. This includes Delta 2, Delta 4, and Atlas 5-class payloads as well as smaller USAF and commercial payloads as required.

The spaceport has received limited financial support from the state in the form of grants. In 2000, it received about $180,000 to upgrade the east breech load doors in the IPF transfer tower. The modification was completed in March 2001. The new transfer tower can accommodate 18-meter (60-foot) payloads. This will enable SSI to process and encapsulate satellites in support of the EELV program. In May 2001, SSI received approximately $167,000 to upgrade the satellite command and telemetry systems. The state of California has also provided some support for California Spaceport business. In 2001, legislation was passed to remove the "sunset" clause on tax exemptions for commercial satellites and boosters launched from VAFB, including California Spaceport.

The California Spaceport provides payload processing and orbital launch support services for commercial, civil, and government users, including

EELV customers. The California Spaceport provided payload-processing services for NASA satellites including Landsat 7 (1996), TIMED/Jason (2001), and Aqua (2002). The California Spaceport's first polar launch was JAWSAT, a joint project of the Air Force Academy and Weber State University, on a Minotaur space launch vehicle in July 2000. To date, the site has launched three Minotaur launch vehicles, most recently in September 2005. In 2002, SSI won a 10-year USAF satellite-processing contract for Delta 4 class 4- and 5-meter (13- and 16-foot) payloads. This contract complements an existing 10-year NASA payload-processing contract for Delta 2 class 3-meter (10-foot) payloads. SSI is working with several launch providers for National Missile Defense support.

The National Reconnaissance Office has contracted with SSI to provide payload processing until 2011. This includes Delta 4 and Atlas 5 EELV-class payload processing support for multiple missions to be launched from VAFB. NASA and commercial Delta-class payloads are also processed at the IPF for launch on the Delta 2 and launched from SLC-2W on VAFB. In 2003 through 2004, the California Spaceport continued improvements to the IPF and supported USAF Pathfinders, including the EELV 5 M Pathfinder. In 2004, SSI was awarded three new Minotaur launches for 2005 and 2006, and a new Indefinite Delivery/Indefinite Quantity contract to support future Minotaur task orders.[46]

In 2005, SSI supported two payload processing flows through the Integrated Processing Facility and two successful Minotaur launches from SLC-8. A third Minotaur is scheduled for launch in March 2006.[47] A new gantry was also installed at SLC-8 in 2005.

### Kodiak Launch Complex

In 1991, the Alaska state legislature created the Alaska Aerospace Development Corporation (AADC) as a public company to develop aerospace-related economic, technical, and educational opportunities for the state of Alaska. In 2000, the AADC completed the $40-million, two-year construction of the Kodiak Launch Complex at Narrow Cape on Kodiak Island, Alaska. The first licensed launch site not co-located with a federal facility, Kodiak Launch Complex (KLC) was also the first new U.S. launch site built since the 1960s. Owned by the state of Alaska and operated by the AADC, the Kodiak Launch Complex received initial funding from the USAF, U.S. Army, NASA, the state of Alaska, and private firms. Today, it is self-sustaining through launch revenues and receives no state funding; the state of Alaska provides tax-free status and has contributed the land that the spaceport resides on.

Athena Launch Pad 1

Kodiak provides a wide launch azimuth and unobstructed downrange flight path. Kodiak's markets are military launches, government and commercial telecommunications, remote sensing, and space science payloads weighing up to 1,000 kilograms (2,200 pounds). These payloads can be delivered into LEO, polar, and Molniya elliptical orbits. Kodiak is designed to launch up to Castor 120-based vehicles, including the Athena 1 and 2, and has been used on a number of occasions to launch military suborbital rockets.

Kodiak facilities currently include the Launch Control Center; the Payload Processing Facility, which includes a class-100,000 clean room, an airlock, and a processing bay; the Launch Service Structure and orbital Launch Pad 1; the Spacecraft and Assemblies Transfer Facility and suborbital Launch Pad 2; the Integration and Processing Facility; and the Maintenance and Storage Facility. These facilities allow the transfer of vehicles and payloads from processing to launch without exposure to the outside environment. This capability protects both the vehicles and the people working on them from exterior conditions, and allows all-weather launch operations.

Kodiak has conducted eight launches since 1998. The first launch from Kodiak was a suborbital vehicle, Atmospheric Interceptor Technology 1, built by Orbital Sciences Corporation for the USAF in November 1998. A second launch followed in September 1999. In March 2001, a Quick Reaction Launch Vehicle (QRLV) was launched from the Kodiak Launch Complex. A joint NASA-Lockheed Martin Astronautics mission on an Athena 1 was the first orbital launch from Kodiak, taking place on September 29, 2001. In November 2001, a Strategic Target System vehicle was launched. However, because of a launch anomaly, the vehicle was destroyed. In April 2002, Orbital Sciences launched a second QRLV for the USAF.

Most recently, on February 13, 2005, MDA launched the IFT-14 target missile, one of several rockets from Kodiak to test the U.S. missile defense system. This followed the 2003 signing of a five-year contract between MDA and AADC to provide launch support services for multiple launches in connection with tests of the nation's missile defense system. The next launch is scheduled for winter of 2006.

The KLC Range Safety and Telemetry System (RSTS) was delivered in September 2003 and upgraded in 2005. The RSTS consists of two fully redundant systems: one for on-site, the other for off-axis. Each part of the RSTS consists of two 5.4-meter (17.7-foot) dishes with eight telemetry links featuring command destruct capabilities. The Kodiak RSTS number 1 system will be located on a newly-constructed multi-elevation antenna field that also supports customer-unique instrumentation. During 2005, Kodiak procured two Mobile Telemetry Systems that will augment the RSTS with additional telemetry receiving capability. Operational evaluation tests have been completed on the RSTS as of September 2005, and certification will be granted upon successful operation as backup to the prime range safety system in 2006.

During 2005, Kodiak completed the Maintenance and Storage Facility with an additional investment of $10 million in grant funding. Future expansion plans include a possible second suborbital launch pad, motor storage facility, and increased fiber-optic bandwidth to the continental U.S. Paving of improved roadways to the Kodiak Launch Complex is scheduled to be completed by 2007.

Located at latitude 57º North, Kodiak Launch Complex occupies a 12.4-square kilometer (4.8-square mile) site about 438 kilometers (272 miles) south of Anchorage and 40 kilometers (25 miles) southwest of the city of Kodiak. The launch site itself encompasses a nearly five-kilometer (three-mile) area around Launch Pad 1.

The AADC is also supporting development of ground station facilities near Fairbanks, Alaska, in cooperation with several commercial remote-sensing companies. The high-latitude location makes the Fairbanks site favorable for polar-orbiting satellites, which typically pass above Fairbanks several times daily.[48]

### Mid-Atlantic Regional Spaceport

Mid-Atlantic Regional Spaceport

The Mid-Atlantic Regional Spaceport (MARS) traces its beginnings to the Center for Commercial Space Infrastructure, created in 1992 at Virginia's Old Dominion University to establish commercial space research and operations facilities in the state. The Center for Commercial Space Infrastructure worked with WFF to develop commercial launch infrastructure at Wallops. In 1995, the organization became the Virginia Commercial Space Flight Authority (VCSFA), a political subdivision of the Commonwealth of Virginia, focused on promoting growth of aerospace business while developing a commercial launch capability in Virginia.

Virginia and Maryland began to cooperatively conduct future development, operate, and promote the MARS under a bi-state agreement executed between the two governors in July 2003. (Hence, the name change from the Virginia Space Flight

Center to MARS). Maryland was provided two seats on the Board of Directors of the Virginia Commercial Space Flight Authority by the Governor of Virginia. Maryland is given equal representation with Virginia members on the Spaceport Committee. Maryland participates with Virginia in funding the operation of the spaceport.[49]

On December 19, 1997, FAA/AST issued VCSFA a launch site operator's license for the MARS. This license was renewed in December 2002 for another five years. The MARS is designed to provide "one-stop shopping" for space launch facilities and services for commercial, government, scientific, and academic users. In 1997, VCSFA signed with NASA a Reimbursement Space Act Agreement to use the Wallops center's facilities in support of commercial launches. This 30-year agreement allows VCSFA access to NASA's payload integration, launch operations, and monitoring facilities on a non-interference, cost reimbursement basis. NASA and MARS personnel work together to provide launch services, providing little, if any, distinction in the areas of responsibility for each.

VCSFA has a partnership agreement with DynSpace Corporation, a Computer Sciences Corporation company, of Reston, Virginia, to operate the spaceport. Funded by a contract with the state and through any spaceport revenues, DynSpace operates MARS for the VCSFA. The state maintains ownership of the spaceport's assets. MARS is located at WFF under a long-term use agreement for real estate on which the Goddard Space Flight Center has made real property improvements. The VCSFA receives the majority of its funding from operations. The remainder of its support comes from the states of Maryland and Virginia (approximately 50 percent of the 2005 operating budget).

VCSFA owns two launch pads at Wallops. Launch pad 0B, its first launch pad, was designed as a "universal launch pad," capable of supporting a variety of small and medium ELVs with gross liftoff weights of up to 225,000 kilograms (496,000 pounds) that can place up to 4,500 kilograms (9,900 pounds) into LEO. Phase 1 construction of launch pad 0B, including a 1,750-square-meter (18,830-square-foot) pad made of reinforced concrete, above-ground flame deflector, and launch mount, took place between March and December 1998. In 2003, MARS committed to the design and construction of a new 34.4-meter (113-foot) Mobile Service Structure. The new $1.3 million Mobile Service Structure offers complete vehicle enclosure, flexible access, and can be readily modified to support specific vehicle operations. The site also includes a complete command, control, and communications interface with the launch range. A USAF OSP Minotaur mission is currently scheduled for this site.

In March 2000, MARS acquired a second pad at WFF, launch pad 0A. EER Systems of Seabrook, Maryland, built this site in 1994 for its Conestoga launch vehicle. The Conestoga made one launch from launch pad 0A in October 1995 but failed to place the METEOR microgravity payload into orbit. MARS started refurbishing launch pad 0A and its 25-meter (82-foot) service tower in June 2000. Launch pad 0A will support launches of small ELVs with gross liftoff weights of up to 90,000 kilograms (198,000 pounds) and that are capable of placing up to 1,350 kilograms (3,000 pounds) into LEO. Completion of the refurbishing project is pending future business opportunities. From its location on the Atlantic coast, MARS can accommodate a wide range of orbital inclinations and launch azimuths. Optimal orbital inclinations accessible from the site are between 38° and 60°; other inclinations, including SSO, can be reached through in-flight maneuvers. Launch pad 0A can support a number of small solid-propellant boosters, including the Athena 1, Minotaur, and Taurus. Launch pad 0B can support larger vehicles, including the Athena 2. MARS also has an interest in supporting future RLVs, possibly using its launch pads or three runways at WFF.[50]

MARS also provides an extensive array of services including the provision of supplies and consumables to support launch operations, facility scheduling, maintenance, inspection to ensure timely and safe ground processing and launch operations, and coordination with NASA on behalf of its customers. Construction of Service Gantry Launch Pad 0B has been completed. MARS is in the process of constructing a $4 million logistics and processing facility at WFF, capable of handling payloads of up to 5,700 kilograms (12,600 pounds); Phase I will be completed in December 2005. The facility, which includes high bay and clean room environments, is currently in construction. In conjunction with WFF, MARS is adding a new mobile Liquid Fueling Facility capable of supporting a wide range of liquid-fueled and hybrid rockets. Construction of the LFF is in the final integration and test phase, with Phase I achieving completion in July 2005.[51]

### Mojave Airport

Mojave Airport

Mojave Airport in Mojave, California, became the first inland launch site licensed by the FAA on June 17, 2004, allowing Mojave Airport to support suborbital launches of RLVs. The East Kern County, California, government established the Mojave Airport in 1935. The original facility was equipped with taxiways and basic support infrastructure for general aviation. A short time after its inception, the Mojave Airport became a Marine Auxiliary Air Station. The largest general aviation airport in Kern County, Mojave Airport is owned and operated by the East Kern Airport District, which is a special district with an elected Board of Directors and a General Manager. The airport serves as a Civilian Flight Test Center, the location of the National Test Pilot School (NTPS), and a base for modifying major military jets and civilian aircraft. The NTPS operates various aircraft, including high-performance jets, single- and twin-engine propeller airplanes, and helicopters. Numerous large air carrier jet aircraft are stored and maintained at the Mojave Airport.

The Mojave Airport consists of three runways with associated taxiways and other support facilities, Runway 12-30, Runway 8-26, and Runway 4-22. Runway 12-30 is 2,896 meters (9,502 feet) long and is the primary runway for large air carrier jet and high-performance civilian and military jet aircraft. Runway 8-26 is 2,149 meters (7,050 feet) long and is primarily used by general aviation jet and propeller aircraft. Runway 4-22 is 1,202 meters (3,943 feet) long and is used by smaller general aviation propeller aircraft and helicopters. Beginning in November 2005, Runway 12-30 will be extended to a total length of 3,810 meters (12,500 feet) through an FAA $7.5 million grant; this extension is a critical element of the spaceport's expansion program aimed at the recovery of horizontal landing RLVs.[52]

Major facilities at the Mojave Airport include the terminal and industrial area, hangars, offices, maintenance shop, and fuel services facilities. Rocket engine test stands are located in the northern portion of the airport. Aircraft parking capacity includes 600 tie downs and 60 T-hangars. The Mojave Airport also includes aircraft storage and a reconditioning facility and is home to several industrial operations, such as BAE Systems, Fiberset, Scaled Composites, AVTEL, XCOR Aerospace, Orbital Sciences Corporation, IOS, and General Electric. Mojave Airport also features several test stands, an air traffic control tower, a rocket test stand, some engineering facilities, and a high bay building.

In the last three years, XCOR Aerospace performed flight tests at this facility, including multiple successful tests with the EZ-Rocket. XCOR Aerospace had three rocketplane test flights up to 3,657 meters (12,000 feet) in 2002. In addition, rocket engines of up to 133,000 newtons (30,000 pounds-force) of thrust were tested at the site in 2002 and 2003. The EZ-Rocket was successfully demonstrated in October 2005 at the Countdown to the X Prize Cup in Las Cruces, New Mexico. In December 2005, the EZ-Rocket made a record-setting point-to-point flight, departing from the Mojave Airport, and gliding to a touchdown at a neighboring airport in California City.[53]

On the 100th anniversary of the Wright Brothers' first powered flight, December 17, 2003, Scaled Composites, LLC, flew SpaceShipOne from Mojave Airport, breaking the speed of sound in the first manned supersonic flight by an aircraft developed privately by a small company. On June 21, 2004, Scaled Composites flew its SpaceShipOne suborbital vehicle from the Mojave Airport, reaching 100 kilometers (62 miles) and becoming

SpaceShipOne

the first private, manned rocket to reach space. SpaceShipOne then flew from Mojave, past the boundary of space, fully loaded to meet the Ansari X Prize qualifications, on September 29 and again on October 4, 2004. Brian Binnie piloted SpaceShipOne to 112 kilometers (69 miles), winning the $10-million Ansari X Prize and smashing the 107,960-meter (354,200-foot) altitude record set by the X-15 airplane in the 1960s.[54]

### Spaceport Operated by Florida Space Authority

Super Loki launch at LC-47

Established by the state of Florida as the Spaceport Florida Authority in 1989, the Florida Space Authority (FSA), renamed as such in January 2002, is empowered like an airport authority to serve the space launch industry and is responsible for statewide space-related economic and academic development. The FSA occupies and operates space transportation-related facilities on approximately .036 square kilometers (.014 square miles) of land at the Cape Canaveral Air Force Station (CCAFS), owned by the United States Air Force (USAF). FAA/AST first issued the state organization a license for spaceport operations on May 22, 1997, and renewed the license in 2002 for another five years.

Under an arrangement between the federal government and FSA, excess facilities at CCAFS have been licensed to FSA for use by commercial launch service providers on a dual-use, non-interference basis. FSA efforts have concentrated on the CCAFS Launch Complex-46 (LC-46), a Trident missile launch site. LC-46 has been modified to accommodate a variety of small launch vehicles, and has already successfully launched the Athena 1 and Athena 2 rockets. With further modifications, LC-46 could accommodate vehicles carrying payloads in excess of 1,800 kilograms (4,000 pounds) to LEO.

Currently, LC-46 is configured for Castor 120 or similar solid-motor-based vehicles. The infrastructure can support launch vehicles with a maximum height of 36 meters (120 feet) and diameters ranging from 1 to 3 meters (3 to 10 feet). An Athena 2, carrying the NASA Lunar Prospector, was the first vehicle launched into orbit from the spaceport in January 1998. This was followed by launch of the ROCSAT satellite on an Athena 1 in January of 1999.

To date, FSA has invested over $500 million in new space industry infrastructure development in Florida. FSA has upgraded LC-46, built an RLV support complex (adjacent to the Shuttle Landing Facility at KSC), and developed a new space operations support complex. Additionally, FSA financed $292 million for Atlas 5 launch facilities at CCAFS LC-41, financed and constructed the $24 million Delta 4 Horizontal Integration Facility for Boeing at LC-37, and provided financing for a Titan 4 solid rocket motor storage and processing facility. Additionally, the state of Florida financed the Space Life Sciences Lab, a $26 million state-of-the-art research facility at KSC.

As part of an overall effort to expand use of the Cape for R&D and educational activities, FSA obtained a five-year license from the Air Force to use LC-47. This launch complex was upgraded to support a significant number of suborbital launch vehicles carrying academic payloads for research and training purposes.

FSA is required by legislation to implement and update the Space Master Transportation Plan, which was developed in 2002 after the Florida Legislature recognized space launch as an official mode of the state's transportation system. The Plan is a continuing work in progress, requiring updating and implementation.

In late 2004, FSA submitted an improved spaceport cargo transportation issue for inclusion in the Brevard County's Fiscal Year 2005-2009 Transportation Improvement Program. The creation of this five-year transportation plan is required by the Florida Department of Transportation (FDOT) to identify transportation-related improvements to the Spaceport and its intermodal connections to the surrounding community. FSA continued to support its request for an additional lane on the existing I-95 exit ramp for improved ingress and egress (eastbound towards the Spaceport) to State Road 407 (SR 407) for space-related cargoes. FSA supported the FDOT throughout the year to justify the redesign of SR 407/ I-95 interchange as a space-related transportation project in Brevard County's TIP. This project, which has been linked with the County's top priority project, the six-lane widening of I-95, is considered a part of Florida's Strategic Intermodal System (SIS). The project's preliminary study phase is complete and will enter the design phase in later years.

The state of Florida has continued to take great strides to include space planning in all of its long-term transportation planning efforts and has looked to FSA to provide space policy advice. In 2005, FSA Executive Director Capt. Winston Scott was appointed to sit on the Florida Transportation Plan (FTP) Update Steering Committee. The FTP is the long-range plan that identifies Florida's transportation system's goals and objectives for the next 20 years. The FTP addresses needs of the entire state transportation system and provides the policy framework for allocating over $100 billion in funding to be spent on meeting the transportation needs of residents, tourists and business people through 2025. FSA's presence on the steering committee facilitated the FDOT's inclusion of space needs in upcoming planning processes.

FSA is in the inception stage of developing an innovative, flexible and cost-friendly "Commercial Spaceport" within the state of Florida to attract commercial launch companies to the state. This commercial spaceport is also intended to accommodate the growing need for rapid response launch vehicles and the launching of smaller payloads for government, commercial and academic users. During 2005 FSA conducted a study to determine the feasibility and economic benefits of developing a commercial spaceport in Florida. The analysis included a market assessment of the number and types of launch vehicles that could possibly use such a facility, and concluded that a new commercial spaceport is feasible from both a market and technical standpoint. In the next decade, a Florida commercial spaceport is expected to primarily benefit economically from the suborbital space tourism market, which will generate increased economic activity, earnings, and jobs, and raise Florida's profile as a space state.

FSA is investigating the possibility of having specific Florida airports apply for an FAA Launch Operators license to support horizontally-launched spacecraft. FSA believes this will be beneficial in attracting space tourism companies utilizing horizontal launch technology, such as Richard Branson's Virgin Galactic. Several statewide airports have shown great interest in participating in space tourism.

## Federal Spaceports

Since the first licensed commercial orbital launch in 1989, the federal ranges have continually supported commercial launch activity. The importance of commercial launches is evident in the changes taking place at federal launch sites. Launch pads have been developed with commercial, federal, and state government support at the two major federal sites for U.S. orbital launches for the latest generation of the Delta and Atlas launch vehicles, including the EELVs. Cape Canaveral Spaceport (consisting of CCAFS and NASA KSC) hosts pads for Delta 2, Delta 4, and Atlas 5. VAFB currently accommodates the Delta 4, and a pad to support the Atlas 5 completed construction in 2005.

Recognizing that the ranges are aging, the U.S. government is engaged in range modernization. This effort includes the ongoing Range Standardization and Automation program, a key effort to modernize and upgrade the Eastern Launch and Test Range at CCAFS and the Western Range at VAFB. The USAF, Department of Commerce, and FAA signed a Memorandum of Agreement in January 2002 that established a process for collecting commercial sector range support and modernization requirements, communicating them to the USAF, and considering them in the existing USAF requirements process. Table 5 summarizes the characteristics of federal spaceports.

### Cape Canaveral Air Force Station

The 45th Space Wing, headquartered at nearby Patrick AFB, conducts launch operations and provides range support for military, civil, and commercial launches at the Cape Canaveral Air Force Station (CCAFS). The 45th Space Wing is the host organization for Patrick AFB, CCAFS, Antigua Air Station, Ascension Auxiliary Air Field, and many mission partners. The Wing is part of Air Force Space Command at Peterson AFB, Colorado, and reports to the 14th Air Force at VAFB.

The Wing manages the Eastern Launch and Test Range (ELTR), provides launch and tracking facilities, safety procedures and test data to a wide variety of users. It also manages launch operations for DoD space programs. Users include the USAF, Navy, NASA, and various private industry contractors. The ELTR also supports Shuttle launches from NASA KSC.

With its mission partners, the Wing processes a variety of satellites and launches them on Atlas 5, Delta 2, and Delta 4 ELVs. The Wing also provides support for the Space Shuttle program and U.S. Navy submarine ballistic missile testing.

The 45th Space Wing was established November 12, 1991. Its origins date back to 1950 with the Army and Air Force's establishment of the Joint Long Range Proving Ground. A year later, the Air Force assumed full control of the new facility, designating it the Air Force Missile Test Center. In 1964, it was renamed the Air Force Eastern Test Range, and in 1979 it became the Eastern Space and Missile Center. The Eastern Space and Missile Center became part of Air Force Space Command in October 1990 when the Air Force transferred space and launch responsibilities from Air Force Systems Command to Air Force Space Command.

Cape Canaveral Air Force Station

Today, CCAFS encompasses active launch complexes for Delta 2, Delta 4, Atlas 5, and sounding rocket launch vehicles. Launch Complex 40 for Titan 4 and Launch Complex 36 for Atlas 2/3 were deactivated in 2005.

**Table 5: Federal Spaceports Infrastructure and Status**

| Spaceport | Location | Owner/Operator | Launch Infrastructure | Development Status |
|---|---|---|---|---|
| Cape Canaveral Air Force Station (CCAFS) | Cape Canaveral, Florida | U.S. Air Force | Telemetry and tracking facilities, jet and Shuttle capable runways, launch pads, hangar, vertical processing facilities, and assembly building. | RLV and ELV spaceport is operational. |
| Edwards AFB | California, near Mojave | U.S. Air Force | Telemetry and tracking facilities, jet and Shuttle capable runways, operations control center, movable hangar, fuel tanks, and water tower. | Site is operational. |
| NASA Kennedy Space Center | Cape Canaveral, Florida | NASA | Launch pads, supporting Space Shuttle operations, the Vehicle Assembly Building (VAB), and the Shuttle Landing | Site is operational. |
| Reagan Test Site | Kwajalein Island, Republic of the Marshall Islands | U.S. Army | Telemetry and tracking facilities, range safety systems, runway, control center. | Site is operational. |
| Vandenberg AFB | Vandenberg AFB, California | U.S. Air Force | Launch pads, vehicle assembly and processing buildings, payload processing facilities, telemetry and tracking facilities, control center engineering, user office space, Shuttle-capable runways. | VAFB has agreements with several commercial companies. Existing infrastructure is operational. Operational EELV pads in 2005. |
| Wallops Flight Facility | Wallops Island, Virginia | NASA | Telemetry and tracking facilities, heavy jet-capable runway, launch pads, vehicle assembly and processing buildings, payload processing facilities, range control center, blockhouses, large aircraft hangars, and user office space. | Site is operational supporting many suborbital flight projects annually, with several orbital missions planned beginning in 2006. Mobile liquid fueling facility under development. |
| White Sands Missile Range | White Sands, New Mexico | U.S. Army | Telemetry and tracking facilities, runway engine and propulsion testing facilities. Class-100 clean room for spacecraft parts. | NASA flight test center is operational. RLV-specific upgrades will probably be required. Signed a Memorandum of Agreement with State of New Mexico regarding cooperation on Southwest Regional Spaceport project. |

The ELTR is used to gather and process data on a variety of East Coast launches and deliver it to range users. To accomplish this task, the range consists of a series of tracking stations located at CCAFS, Antigua Air Station, and Ascension Auxiliary Air Field. The range also uses the Jonathan Dickinson and the Malabar Tracking Annexes on the Florida mainland. These stations may be augmented with a fleet of advanced range instrumentation aircraft as well as a site located in Argentia, Newfoundland.[55]

The CCAFS supported six launches through December 2005, including the NASA Mars Reconnaissance Orbiter satellite on an Atlas 5; the Inmarsat 4-F1 commercial telecommunications satellite, also on an Atlas 5; and a National Reconnaissance Office payload on the last Atlas 3B.

### Edwards Air Force Base

Edwards Air Force Base

Located in California, Edwards Air Force Base (EAFB) is the home of more than 250 first flights and about 290 world records. It was the original landing site for the Space Shuttle. The first two Shuttle flights landed on Rogers Dry Lake, a natural hard-pack riverbed measuring about 114 square kilometers (44 square miles). Unfortunately, the normally dry lakebed was flooded in 1982, rendering the site unavailable for the third Shuttle landing. (The Space Shuttle landed at White Sands, New Mexico instead.) Today, NASA prefers to use KSC as the primary landing site for the Space Shuttle and uses EAFB as a back-up site. Today EAFB is DoD's premier flight test center, leading in unmanned aerial vehicle (UAV), electronic warfare, and directed energy test capabilities.

Within the last five years, EAFB has been the home of more than 10 experimental projects, among them the X-33 airplane. Before its cancellation, the X-33 airplane was to use EAFB as a test site. In December 1998, NASA completed construction of a launch site at EAFB. The site consisted of an X-33-specific launch pad, a control center to be used for launch monitoring and mission control, and a movable hangar where the vehicle was to be housed and serviced in a horizontal position. The site was equipped with hydrogen and nitrogen gas tanks, as well as liquid hydrogen and oxygen tanks capable of holding more than 1.1 million liters (291,000 gallons) of cryogenic materials.

Today Edwards is the home of the F/A-22 Raptor; the X-43 Hyper-X; the X-45 JUCAS, a UAV; and the Airborne Laser system.[56]

The federal government is investing several million dollars to refurbish and modernize two large scale rocket test stands at the AFRL's Edwards Research Site. One is a component test stand and the other is an engine test stand. Plans are also being developed to continue refurbishing additional rocket stands in the future for purposes of rocket testing.

EAFB, along with NASA's co-located, premier aeronautical flight research facility, Dryden Flight Research Center, hosts other NASA reusable X-vehicle demonstration programs. In 2001, NASA used a Pegasus XL launch vehicle to conduct a test of the X-43A demonstrator. NASA used a helicopter to conduct seven successful X-40A flight tests during 2001. In 2004, NASA transferred the X-37 program to DARPA, which is expected to conduct drop tests in 2005.

### NASA Kennedy Space Center

NASA KSC LC-39B

Established as NASA's Launch Operations Center in July 1962, Kennedy Space Center (KSC) today serves as the primary launch site for NASA's manned space missions. Major KSC facilities comprise LC-39B, supporting Space Shuttle operations; the Vehicle Assembly Building (VAB), where the

Shuttle is integrated; and the Shuttle Landing Facility. NASA's expendable launch vehicles are flown primarily from CCAFS and VAFB with support from the USAF. Additional rocket flights are conducted from WFF, Kodiak Launch Complex, and the Reagan Test Site.

Space Shuttle Discovery's return to flight mission launched from KSC on July 26, 2005, after a two-and-a-half year hiatus during which Shuttle thermal protection systems were redesigned for enhanced safety and reliability.

### Reagan Test Site

Kwajalein Island

Located in Kwajalein Island, part of the Republic of the Marshall Islands, the U.S. Army's Reagan Test Site (RTS) is within the DoD Major Range and Test Facility Base. The advantages of RTS include its strategic geographical location, unique instrumentation, and capability to support ballistic missile testing and space operations. RTS is completely instrumented to support space launch customers with radar, telemetry, optics, and range safety systems. With nearly 40 years of successful support, RTS provides a vital role in the research, development, test, and evaluation effort of America's missile defense and space programs. RTS currently supports space launch operations for Orbital Sciences Corporation, SpaceX, and the Missile Defense Agency (MDA). Orbital Sciences Corporation will be launching a Pegasus rocket with the USAF C/NOFS payload in 2006. SpaceX will be launching its Falcon 1 launch vehicle with the USAF FalconSat-2 payload in early 2006.[57]

### Vandenberg Air Force Base


Vandenberg Air Force Base

In 1941, the U.S. Army activated this site near Lompoc, California, as Camp Cook. In 1957, Camp Cook was transferred to the Air Force, becoming the nation's first space and ballistic missile operations and training base. In 1958, it was renamed VAFB in honor of General Hoyt S. Vandenberg, the Air Force's second Chief of Staff. VAFB is currently the headquarters of the 30th Space Wing and the Air Force Space Command organization responsible for all DoD space and missile activities for the West Coast. All U.S. satellites destined for near-polar orbit launch from the Western Range at VAFB. The 30th Space Wing, Range Operations Control Center, provides flight safety, weather, scheduling, and instrumentation control, along with target designation information and tracking data to and from inter- and intra-range sensors in real or near-real-time for missile and space launch support. Range tracking capabilities extend over the Pacific Ocean as far west as the Marshall Islands, with boundaries to the north as far as Alaska and as far south as Central America. Vandenberg is host to the 14th Air Force Headquarters.

VAFB infrastructure used for space launches includes a 4,500-meter (15,000-foot) runway, boat dock, rail lines, launch facilities, payload processing facilities, tracking radar, optical tracking and telemetry facilities, and control centers. The 401-square-kilometer (155-square-mile) base also houses numerous government organizations and contractor companies in over 1,000 buildings. VAFB hosts a variety of federal agencies and attracts commercial aerospace companies and activities, including the California

Spaceport effort. The 30th Space Wing supports West Coast launch activities for the USAF, DoD, NASA, and various private industry contractors. For the development of launch infrastructure for the EELV program, VAFB has partnered with Boeing and Lockheed Martin. Boeing has renovated Space Launch Complex 6 (SLC-6) from a Space Shuttle launch pad into an operational facility for Delta 4. Construction at SLC-6 has included enlarging the existing mobile service tower and completing the construction of the West Coast Horizontal Integration Facility, where the Delta 4 is assembled.

Current launch vehicles using VAFB include Delta 2, Delta 4, Titan 4, Atlas 5, Taurus, Minotaur, Pegasus XL; and Falcon 1 families. NASA operates SLC-2, from which Boeing Delta 2 vehicles are launched. The first Delta 4 launch from Vandenberg is planned for 2006.[58] The final Titan 4B was launched from SLC-4E in October 2005.

Lockheed Martin has renovated SLC-3E from an Atlas 2 launch pad into an operational facility for Atlas 5. The upgrades started in January 2004, which include adding 9 meters (30 feet) to the existing 61-meter (200-foot) mobile service tower to accommodate the larger rocket and replacing the crane capable of lifting 20 tons with a crane that can lift 60 tons. The first Atlas 5 launch from Vandenberg is planned for 2006 and will deploy a classified payload for the National Reconnaissance Office (NRO).

Orbital Sciences Corporation's Taurus is launched from 576-E. Pegasus XL vehicles are processed at Orbital Sciences' facility at VAFB then flown to various worldwide launch areas. Minotaur is launched from the California Spaceport and has plans for two launches in the next two years. The DARPA Streak satellite was successfully launched on a Minotaur from SLC-8 in September 2005. A new commercial launch vehicle, Falcon, being developed by SpaceX, plans to launch from VAFB in 2006.

During 2005, Lockheed Martin "safed" and deactivated SLC-4 West, which served as the launch pad for Titan 2 since 1988, under a $3-million Air Force contract. SLC-4 East, which hosted the Titan 4, saw its final launch in October 2005, after which it will be used to support responsive launch vehicles. The USAF will dismantle portions of the site no longer needed for future vehicles in 2006. Finally, the last Peacekeeper launch, scheduled for May 2005, was cancelled, and the Peacekeeper program has been deactivated at 30th Space Wing. Vandenberg supports numerous ballistic programs including Minuteman, Peacekeeper and MDA test/operational programs.

VAFB is also upgrading its range instrumentation and control centers to support the space launch industry. Scheduled for completion by 2010, these upgrades will automate the Western Range and provide updated services to the customer.

At this time, VAFB has active partnerships with seven private commercial space organizations in which VAFB provides launch property and launch services. The private companies use the government or commercial facilities to conduct payload and booster processing work. VAFB houses three commercially-owned facilities/complexes: Boeing's Horizontal Integration Facility, Spaceport Systems International's (SSI) California Spaceport and Payload Processing Facility, and Astrotech's Payload Processing Facility.[59]

### Wallops Flight Facility

Wallops Flight Facility

The National Advisory Committee for Aeronautics, the predecessor of NASA, established an aeronautical and rocket test range at Wallops Island, Virginia, in 1945. Since then, over 15,000 rocket launches have taken place from the WFF, which is operated for NASA by the Goddard Space Flight Center, Greenbelt, Maryland.

WFF's primary mission is to serve as a research and test range for NASA, supporting scientific research, technology development flight testing, and educational flight projects. WFF, however, also heavily supports the Department of Defense (DoD) and commercial industry with flight projects ranging from small suborbital vehicles to orbital launch vehicles. In addition to rockets, WFF's integrated Launch Range & Research Airport enables flight operations of UAVs and other experimental craft. WFF also frequently serves as a down-range site for launches conducted from Cape Canaveral.

The first orbital launch occurred in 1960, when a Scout launch vehicle deployed Explorer 9 to study atmospheric density. There have been 29 orbital flight attempts from Wallops. The retired Scout made its last orbital launch from WFF in 1985. Since then, WFF has supported the launch of the launch of the Conestoga 1620 in 1995 as well as numerous Pegasus missions. Additionally, WFF's fully-capable Mobile Range has supported orbital launches from the worldwide locations, including a Pegasus from the Canary Islands in 1997 and a Lockheed Martin Athena 1 from Kodiak, Alaska, in 2001. The Near-Field Infra-Red Experiment is scheduled for launch from Wallops in 2006, and other Minotaur-class missions are under consideration.

WFF is also heavily engaged in supporting both DoD and commercial interests in the emerging small ELV community, such as those supported by the DARPA FALCON program. During 2005, WFF's Research Range supported in excess of 700 flight projects, ranging from rocket launches to aircraft and UAV fight tests; of these events, approximately 50 were rocket-related.

MARS is co-located at WFF as a tenant, and the organizations collaborate on certain projects to jointly provide mission services, particularly focusing on small commercial ELVs. Jointly, WFF and MARS offer two orbital and numerous suborbital launch pads, a range control center, three blockhouses, numerous payload and vehicle preparation facilities, and a full suite of tracking and data systems. In support of its research and program management responsibilities, Wallops also contains numerous science facilities, a research airport, and flight hardware fabrication and test facilities.

WFF continues a significant range modernization and technology program, begun in 2002, involving upgrades to its Range Control Center and tracking systems, a new 1,115-square-meter (12,000-square-foot) multi-user high-bay payload processing and integration facility, and a mobile liquid fueling system. WFF engineers are also actively pursuing new range technologies that will increase responsiveness and lower costs, such as space-based communications systems and an autonomous flight termination system.[60]

### White Sands Missile Range

White Sands Missile Range

Once exclusively military, White Sands Missile Range today attracts other government agencies, foreign nations, and private industry to its world-class test facilities. It is the largest overland test range in America, operated by the U.S. Army and includes agencies such as at NASA's White Sands Test Facility. Situated 26 kilometers (16 miles) northeast of Las Cruces, New Mexico, the range covers 8,100 square kilometers (3,127 square miles).

Since its establishment in 1945, the range has fired more than 44,500 missiles and rockets. Almost 1,200 of those were research and sounding rockets. White Sands has seven engine test stands and precision cleaning facilities, including a class-100 clean room for spacecraft parts.

Test operations are run out of the new J.W. Cox Range Control Center. This $28-million facility was designed to meet current and future mission requirements with the latest networking, computing and communications for effective interaction between test operations and customers.

White Sands is also the Space Shuttle's tertiary landing site after KSC and EAFB. This landing site consists of two 11-kilometer (6.8-mile) long, gypsum-sand runways.[61]

In 2002, the U.S. Army/WSMR and the state of New Mexico signed a Memorandum of Agreement supporting the development of the Southwest Regional Spaceport. This agreement enables the spaceport to share resources and integrate launch scheduling and operations with the U.S. Army test range.

## Proposed Non-federal Spaceports

Several states plan to develop spaceports offering a variety of launch and landing services. Two common characteristics of many of the proposed spaceports are inland geography—a contrast to the coastal location of all but one present-day U.S. spaceports—and interest in hosting RLV operations. Table 6 describes specific efforts to establish non-federal spaceports, which are in various stages of development.

### Gulf Coast Regional Spaceport

Amateur Rocket Launch at GCRS Site

The Gulf Coast Regional Spaceport Development Corporation (GCRSDC) has proposed constructing a spaceport in Brazoria County, Texas, 80 kilometers (50 miles) south of Houston. The Corporation has identified undeveloped land currently used for agriculture as a potential site and is working with the private owner of the land to acquire or lease the property.

The GCRSDC has in place a phased plan for development, and is currently focused on short-term goals of creating infrastructure and securing an FAA license for suborbital missions. Phase I and Phase II of the suborbital licensing process has been completed, using government funding for site selection, environmental analysis, and an in-depth safety analysis of the site based on the use of different types of launch systems. Brazoria County is putting in a road and launch platform, along with a launch control facility. Mission control will be linked by satellite to nearby Brazosport College. In the long term, the spaceport aims to support orbital launches to either polar or equatorial orbits.

Local governments invested nearly $300,000 in the project between 1999 and 2001, primarily for site selection work. In February 2002, the state approved the Gulf Coast Regional Spaceport board's access to the first installment of $500,000 in state grant money. The initial $150,000 paid contractor fees for an in-depth safety analysis of the site based on the use of different types of launch systems. The draft development plan has greatly assisted in determining what infrastructure is necessary.[62] In 2005, the State of Texas awarded the GCRSP a grant for $325,000 and the new scope of work has been approved.[63]

The Amateur Spaceflight Association (ASA) launched a 3.7-meter (12-foot) long amateur rocket from this site in May 2003, and negotiations are underway with ASA, Texas A&M University, and several commercial space operations for launch and/or recovery missions. The web site for the spaceport is www.gulfcoastspaceport.com.

### Oklahoma Spaceport

The state of Oklahoma is developing a broader space industrial base and a launch site. In 1999, the Oklahoma state legislature created the Oklahoma Space Industry Development Authority (OSIDA). Directed by seven governor-appointed board members, OSIDA promotes the development of spaceport facilities and space exploration, education, and related industries in Oklahoma. Currently, the state of Oklahoma provides operating costs for OSIDA, but the organization expects to be financially independent in less than five years. In 2000, the Oklahoma state legislature passed an economic incentive law offering tax credits, tax exemptions, and accelerated depreciation rates for commercial spaceport-related

Table 6: Proposed Non-federal Spaceports: Infrastructure and Status

| Spaceport | Location | Owner/Operator | Launch Infrastructure | Development Status |
|---|---|---|---|---|
| Gulf Coast Regional Spaceport | Brazoria County, Texas | To be determined | Road, suborbital launch platform, launch control facility. | The Gulf Coast Regional Spaceport Development Corporation has proposed constructing a spaceport in Brazoria County, Texas, 80 kilometers (50 miles) south of Houston. FAA suborbital launch site licensing process is underway. |
| Oklahoma Spaceport | Washita County, Oklahoma | Oklahoma Space Industry Development Authority | 4,115-meter (13,500-foot) runway, a 5,200-square-meter (50,000-square-foot) manufacturing facility, a 2,7850-square-meter (30,000-square-foot) maintenance and painting hangar, 6 commercial aircraft hangars including a 2,787 square meter (30,000 square foot) maintenance and paint facility, 39 hectares (96 acres) of concrete ramp, control tower, crash and rescue facility, and 435 square kilometers (168 square miles) of land available for further construction. | The Clinton-Sherman AFB at Burns Flat was designated as the future spaceport. OSIDA is conducting a safety study of the proposed site and operations. An environmental impact study is underway. |
| South Texas Spaceport | Willacy County, Texas | To be determined | No infrastructure at this time. | The final Texas Spaceport site has not been selected. Three sites are being considered at this time. Suborbital rockets have been launched near the proposed site. |
| Southwest Regional Spaceport | Upham, New Mexico | New Mexico Spaceport Authority | No infrastructure at this time. | Plans for this site include a spaceport central control facility, an airfield, a maintenance and integration facility, a launch and recovery complex, a flight operations control center, and a cryogenic plant. Environmental and business development studies conducted. |
| Spaceport Alabama | Baldwin County, Alabama | To be determined | No infrastructure at this time. | The master plan phase 1 has been completed. Phase 2 is expected to be completed by October 2005. While no land has been acquired for Spaceport Alabama, a green field site is under consideration in Baldwin County, across the bay from the city of Mobile. |
| Spaceport Washington | Grant County International Airport, Washington | Port of Moses Lake | 4,100-meter (13,452-foot) main runway and a 3,200-meter (10,500-foot) crosswind runway. | A 121 square kilometer (30,000 acre) potential vertical launch site has been identified. An Aerospace Overlay Zone has also been established in the Grant County Unified Development Code. The site is certified as an emergency-landing site for the Space Shuttle. Additional infrastructure development is pending launch customers and market responses. |
| West Texas Spaceport | Pecos County, Texas | Pecos County/West Texas Spaceport Development Corporation | Greasewood site has an air conditioned control center, an industrial strength concrete pad, and a 30 x 30 meter (100 x 100 ft.) scraped and level staging area. Broadband Internet on site, controlled fenced access, and a 1,295 square kilometer (500 square mile) recovery area. Airport has 5 runways (2,286 x 30 meter, or 7,500 x 100 ft.) with hangar space. | Development plan approved by State of Texas in 2005. State has provided $175K in 2005 for planning studies. Future infrastructure plans include 3,500 foot runway, static engine testing facility, and balloon hangar. |
| Wisconsin Spaceport | Sheboygan, Wisconsin | Owner: City of Sheboygan; Operator: Rockets for Schools | A vertical pad for suborbital launches in addition to portable launch facilities, such as mission control. | Plans for developing additional launch infrastructure are ongoing and include creation of a development plan that includes support for orbital RLV operations. Legislation creating the Wisconsin Aerospace Authority is pending. |

Oklahoma Spaceport

activities. In 2002, OSIDA, through a third-party agreement with the FAA, awarded a contract to SRS Technologies and C.H. Guernsey to prepare an environmental assessment. The analysis, completed in 2006, is a critical step toward receiving a launch site operator license from FAA/AST.

Clinton-Sherman Industrial Airpark (CSIA), located at Burns Flat, is the preferred site for a future launch site in Oklahoma. Existing infrastructure includes a 4,100-meter (13,500-foot) runway, large maintenance and repair hangars, utilities, rail spur, and 12.4 square kilometers (4.8 square miles) of open land. The city of Clinton has agreed to convey ownership of the CSIA to OSIDA upon issuance of a launch site operator license from FAA/AST. The FAA Southwest Region has reviewed and approved the transfer upon completion of the EIS and other contingencies. The launch activities proposed will not greatly impact the continued use of the CSIA as an active airport for USAF training and for general aviation. Oklahoma Spaceport will provide launch and support services for horizontally launched RLVs and may become operational in 2006.

Oklahoma offers several incentives, valued at over $128 million over 10 years, to attract space companies. For example, a jobs program provides quarterly cash payments of up to five percent of new taxable payroll directly to qualifying companies for up to 10 years. Organizations also may qualify for other state tax credits, tax refunds, tax exemptions, and training incentives. Rocketplane Limited and TGV Rockets, Inc. have located in Oklahoma for their launch vehicle developments. As the first corporation that met specific qualifying criteria, including equity capitalization of $10 million and creation of at least 100 Oklahoma jobs, Rocketplane Limited qualified for a $15-million, state-provided tax credit in early 2004.

Besides state funding, NASA issued $241,000 to OSIDA for space-related educational grants to be used throughout the state. OSIDA has signed Memoranda of Understanding with several companies for use of the Burns Flat site. It is the goal of the Oklahoma Spaceport to be self-sufficient five years from the date of receiving a launch site operator's license from FAA/AST.[64]

### South Texas Spaceport

Charles R. Johnson Airport

Willacy County Development Corporation was created in 2001 to manage the spaceport site evaluation and other technical and administrative elements of the project under a Texas Aerospace Commission grant. In February 2002, the Texas Aerospace Commission awarded a $500,000 contract to the South Texas Spaceport.

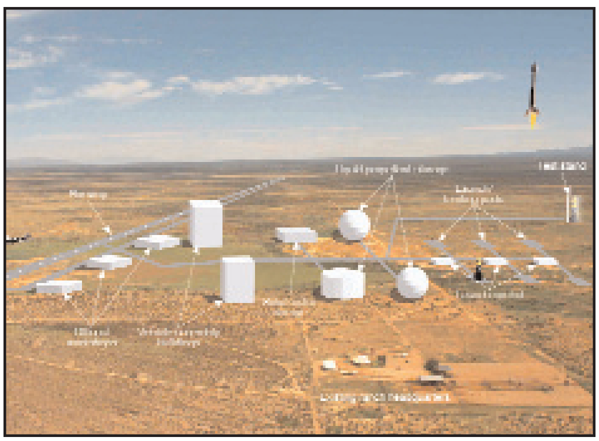
The designated spaceport site is a 405,000-square-meter (0.16-square-mile) undeveloped site adjacent to the Charles R. Johnson Airport in Port Mansfield, approximately 150 kilometers (93 miles) south of Corpus Christi and 65 kilometers (40 miles) north of Brownsville. The site initially may support the suborbital and small orbital launch systems currently in service or being developed for service in the near future, with a long-term focus on RLVs. All launches will be from spoil islands or barges in the Mansfield ship channel in the Laguna Madre or Gulf of Mexico.

In 2003, a 68-kilogram (150-pound) sounding rocket and a 3.4-meter (11-foot) Super Loki suborbital rocket were launched near the site in efforts to generate awareness and encourage state funding of the South Texas Spaceport.

To date, no infrastructure has been built; future infrastructure improvements are focused on development of an all weather road to the site, a 18 by 25 meter (60 by 80 foot) metal building, and utilities. Continuing planning efforts are focused on the infrastructure needed to support activities of launch operators with current development programs.

Recently, Texas Spacelines, Inc., entered into negotiations with the Willacy County Development Corporation for Spaceport Facilities for the establishment of a permanent launch site in South Texas.[65] Willacy County is currently applying for a state grant for the spaceport building next to Port Mansfield. It will include two launch pads and a building as well as all utilities such as water, sewer, road to and from project.[66]

### Southwest Regional Spaceport



Southwest Regional Spaceport

The state of New Mexico continues to make significant progress in the development of the Southwest Regional Spaceport (SRS). Building on its May 2004 winning bid to host the X Prize Cup competition, a future international exhibition created by the X Prize Foundation, New Mexico inaugurated this annual event with the Countdown to the X Prize Cup event in Las Cruces in October 2005. The Countdown and associated Personal Spaceflight Expo at New Mexico State University attracted industry and government attendees from the U.S., Europe, and Japan.

The SRS is being developed for use by private companies and government organizations conducting space activities and operations. The proposed site of the spaceport is a 70-square-kilometer (27-square-mile) parcel of open land in the south central part of the state at approximately 1,430 meters (4,700 feet) above sea level. The spaceport concept is to support all classes of RLVs serving suborbital trajectories as well as equatorial, polar, and ISS orbits, and to provide support services for payload integration, launch, and landing. The facility will be able to accommodate both vertical and horizontal launches and landings as well as air and balloon launches. In addition, this facility will include multiple launch complexes, a runway, an aviation complex, a payload assembly complex, other support facilities, and, eventually, a cryogenic fuel plant.

The SRS is supported by the state through the New Mexico Office for Space Commercialization, part of the New Mexico Economic Development Department. In 2002, the state and the U.S. Army White Sands Missile Range signed a Memorandum of Agreement supporting the development of the SRS. This agreement enables the spaceport to share resources and integrate launch scheduling and operations with the U.S. Army test range. During 2004, New Mexico and the X Prize Foundation entered into a long-term partnership to jointly promote emerging commercial space technologies and spaceport concepts. Between 2001 and 2004, the state legislature appropriated $10.5 million for spaceport infrastructure development, including environmental studies and land acquisition, and planning, analysis and operations. The New Mexico Spaceport Authority held its first meeting in August 2005 and expects to receive an FAA spaceport license in 2006.

New Mexico has provided several tax and business incentives for the spaceport-related industrial activities, including gross receipt deductions, exemptions from compensating taxes, R&D incentives, industrial revenue bonds, and investment and job training credits. The first suborbital rocket launch from the spaceport is scheduled for March 2006.[67] In December 2005, the state of New Mexico and Virgin Galactic announced a partnership to secure $225 million to build the spaceport, from which Virgin Galactic plans to operate its passenger-carrying flights on SpaceShipTwo. Virgin has signed a 20-year lease on the spaceport, paying $1 million a year in the first five years and the full cost of operations over the remaining years, while New Mexico will invest $135 million in the spaceport and obtain federal and state funds.

### Spaceport Alabama

Proposed as a next-generation spaceport, Spaceport Alabama will be a full-service departure and return facility supporting orbital and suborbital space access vehicles. Spaceport Alabama is in the planning phase under direction of the Spaceport Alabama Program Office at Jacksonville State University in Alabama. The Spaceport Alabama master planning Phase 1 is now complete, and Phase 2 has commenced. Upon completion of the Spaceport Alabama master plan, which is expected to be by the end of 2006, a proposal will be presented to the Alabama Commission on Aerospace Science and Industry and the Alabama Legislature for formal adoption. Under the current plan, the Alabama Legislature would establish the Spaceport Alabama Authority, which would oversee development of Spaceport Alabama. While no land has been acquired for Spaceport Alabama, a greenfield site is under consideration in Baldwin County, across the bay from the city of Mobile. This site is seen as ideal for supporting government and commercial customers operating next-generation reusable flight vehicles that are designed for access to LEO, MEO, and GEO.[68]

Under the current spaceport development plan, a spaceport facility could become operational within 10 years, depending on market demand. This plan calls for the establishment of a “total spaceport enterprise” concept, consisting of a departure and return facility, processing and support facilities, and full support infrastructure. An R&D park, a commerce park, supporting community infrastructure, intermodal connectivity, and other services and infrastructure necessary for providing a “turn key” capability in support of space commerce, R&D, national security, science, and related services are also included in this plan. Given that the site currently under consideration is adjacent to the Gulf of Mexico, Spaceport Alabama would service primarily RLVs; however, some suborbital ELVs involving scientific and academic missions could be supported. No updates were received from the spaceport for 2005.

### Spaceport Washington

Spaceport Washington

Spaceport Washington, a public/private partnership, has identified Grant County International Airport in central Washington, 280 kilometers (174 miles) east of Seattle, as the site of a future spaceport. The airport (formerly Larson AFB and now owned and operated by the Port of Moses Lake) is used primarily as a testing and training facility. Spaceport Washington proposes to use Grant County International Airport for horizontal and vertical take-offs and horizontal landings of all classes of RLVs. This airport has a 4,100-meter (13,452-foot) main runway and a 3,200-meter (10,500-foot) crosswind runway, and is certified as an emergency landing site for the Space Shuttle.

An approximately 121-square-kilometer (30,000-acre) potential vertical launch site has been identified with multiple ownership (both public and private). The spaceport has also established an Aerospace Overlay Zone within the Grant County Unified Development Code. The purpose of the Aerospace Overlay zoning is to protect the air and land space around the area proposed for use as an aerospace launch and retrieval facility from obstructions or hazards and incompatible land uses in the proximity of the Grant County International Airport. Additional infrastructure development is pending launch customers and market responses.[69]

### West Texas Spaceport

The Pecos County/West Texas Spaceport Development Corporation, established in mid-2001, is moving forward with the development of a spaceport 29 kilometers (18 miles) southwest of Fort Stockton, Texas. Spaceport infrastructure will

West Texas Spaceport

include a launch site with a 4,570-meter (15,000-foot) safety radius, an adjacent recovery zone (193 square kilometers, or 500 square miles), payload integration and launch control facilities, and the Pecos County Airport runway (2,308 meters or 7,500 feet) and hangar complex. The site has access to over 1,738 square kilometers (4,500 square miles) of unpopulated range land, and over 3,861 square kilometers (10,000 square miles) of under-utilized national airspace.

A joint project with the school district has made a state-of-the-art technology center available for Pecos County Aerospace Development Center users. The Technology Center has multiple monitors, high-speed Internet service, and full multiplexing capability. Video can be streamed from the Greasewood or Hudgins launch sites to the Technology Center to accommodate dignitaries and other officials in air-conditioned comfort. The Pecos County/West Texas Spaceport Development Corporation has access to optical tracking and high-speed video capability that can record the vehicle's flight up to tens of thousands of feet (depending upon the vehicle's size) regardless of its speed.[70]

In February 2002, the Texas Aerospace Commission awarded a $500,000 contract to the West Texas Spaceport. In June 2002, the USAF approved the site for various test launch projects. JP Aerospace began launching small suborbital rockets from the site in October 2002. The University of Houston Division of Research Agency awarded the Pecos County/West Texas Spaceport Development Corporation $80,000 for 2003.

During 2005 the following spaceport infrastructure was added: an industrial strength concrete pad, a 31x31 meter (100x100-foot) scraped and level staging area, broadband Internet on site, and controlled fenced access. The state of Texas also approved the spaceport development plan, and provided $175,000 in financial support for planning and development. Flight activity included launches of NASA Dryden's DART suborbital rocket, the TPAE series of suborbital rocket tests, Lockheed Martin UAV tests, and tests of the Air Force Battle Lab Near Space Maneuvering Vehicle.

Future infrastructure plans include the development of a 1,077-meter (3,500 foot) runway, a static engine test facility, and a hangar for balloon and wind sensitive activities. Other projects are being pursued by the Pecos County/West Texas Spaceport Development Corporation. These projects include the Blacksky DART program, intended to characterize the performance of an innovative aerospike nozzle on a solid rocket motor. Texas A&M University's senior-level student aerospace engineering program gives students the opportunity to build and fly an advanced design rocket. In addition, the Texas Partnership for Aerospace Education project supports middle and high school students to send experiments fitted inside ping pong balls on balloons to the edge of space. Additional information on the West Texas Spaceport is available at aerospacetexas.com.[71]

### Wisconsin Spaceport

Spaceport Sheboygan

On August 29, 2000, the Wisconsin Department of Transportation officially approved creation of the Wisconsin Spaceport, located on Lake Michigan in Sheboygan, Wisconsin. The city of Sheboygan owns the spaceport, which strives to support space research and education through suborbital launches for student projects.

Suborbital sounding rocket launches to altitudes of up to 55 kilometers (34 miles) have been conducted at the site. Additionally, Rockets for Schools, a student program founded in Wisconsin by Space Explorers, Inc., and developed by the Aerospace States Association, has conducted suborbital launches at Spaceport Sheboygan since its inception in 1995. Each year, hundreds of students from Wisconsin, Illinois, Iowa, and Michigan participate in these launches, which took place most recently in May 2005. Rockets for Schools is a firmly established, high-quality program of the Great Lakes Spaceport Education Foundation.

The spaceport's existing infrastructure includes a vertical pad for suborbital launches in addition to portable launch facilities, such as mission control, which are erected and disassembled as needed. The pier, which the city leased from the U.S. Army Corps of Engineers for spaceport launches and citizens' enjoyment (i.e. walking and fishing), was widened and strengthened in 2004. Additionally, some structures were removed to clear space for the construction of a proposed mission control and education center.

Plans for developing additional launch infrastructure are ongoing. Future projects include adding orbital launch capabilities for RLVs. Spaceport developers are in the process of creating a development plan. Legislation for the creation of the Wisconsin Aerospace Authority (WAA) was introduced in the Wisconsin legislature in October 2005. The legislation authorizes the WAA to develop spaceports, spacecraft, and other aerospace facilities in Wisconsin, to provide spaceport and aerospace services and allow use of spaceport and aerospace facilities by others, to promote the aerospace industry in Wisconsin, and to provide public-private coordination for the aerospace industry in Wisconsin. Under the current legislation, state funding for the WAA is provided from the Wisconsin Department of Transportation's appropriation for airports and air navigation. At a public hearing in late November, legislation for the WAA received wide-ranging support. The development of the Great Lakes Aerospace Science and Education Center at Spaceport Sheboygan is currently underway.[72]

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