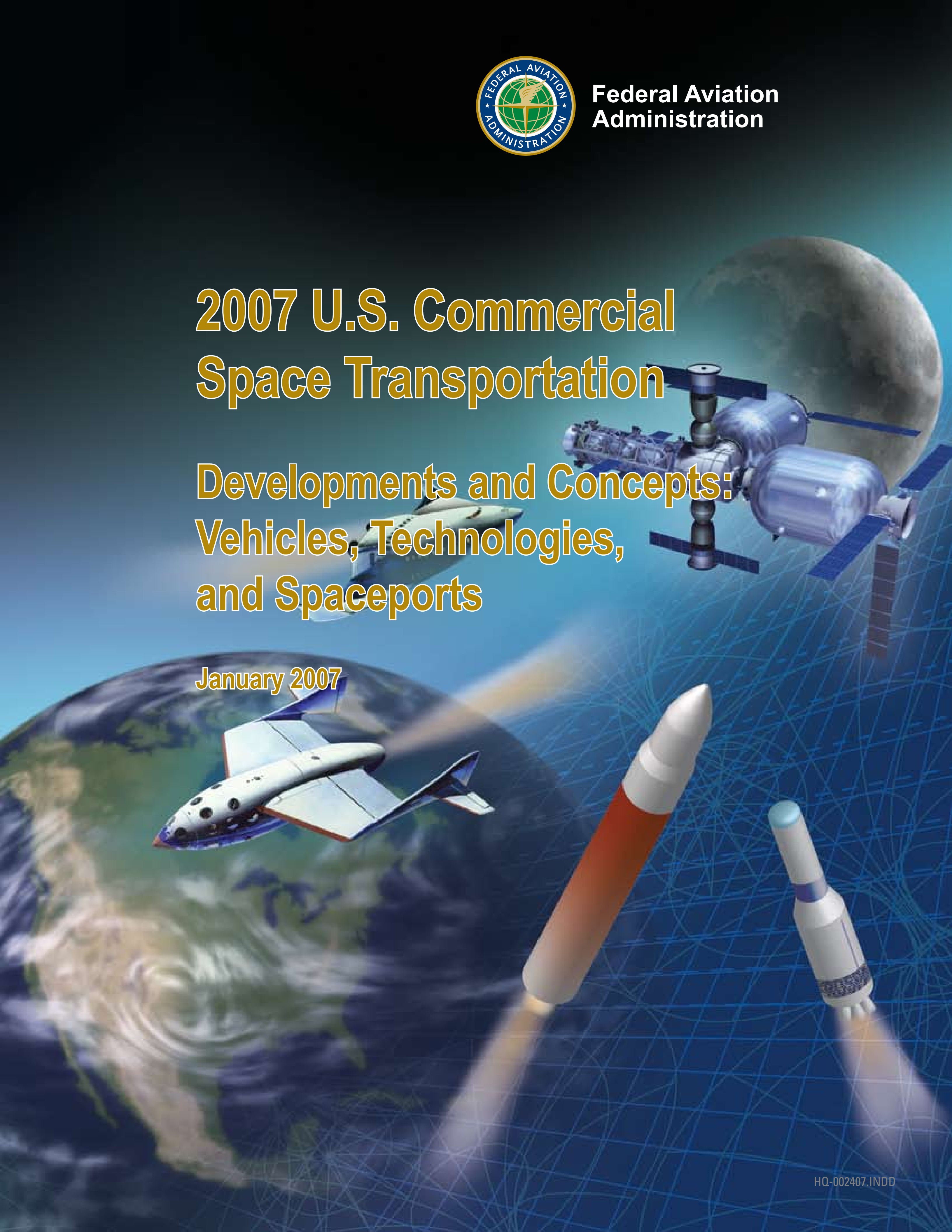
Federal Aviation Administration

2007 U.S. Commercial Space Transportation

Developments and Concepts: Vehicles, Technologies, and Spaceports

January 2007



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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://www.faa.gov/about/office_org/headquarters_offices/ast/.

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List of Acronyms

AADC	Alaska Aerospace Development Corporation
ACES	Air Collection and Enrichment System
AFB	Air Force Base
AFRL	Air Force Research Laboratory
ALV	ATK Launch Vehicle
ARES	Affordable Responsive Spacelift
AST	Office of Commercial Space Transportation (within the FAA)
ATK	Alliant Techsystems
BRAC	Base Realignment and Closure
CALVEIN	California Launch Vehicle Initiative
CCAFS	Cape Canaveral Air Force Station
CEV	Crew Exploration Vehicle
CONUS	Continental United States
COTS	Commercial Orbital Transportation Services
CSIA	Clinton-Sherman Industrial Airpark
CSULB	California State University, Long Beach
DARPA	Defense Advanced Research Projects Agency
DoD	U.S. Department of Defense
EAFB	Edwards Air Force Base
EELV	Evolved Expendable Launch Vehicle
ELTR	Eastern Launch and Test Range
ELV	Expendable Launch Vehicle
ESR&T	Exploration Systems Research and Technology
FAA	Federal Aviation Administration
FALCON	Force Application and Launch from CONUS
FASTT	Freeflight Atmospheric Scramjet Test Technique
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
HTP	High-Test Peroxide
HTPB	Hydroxyl Terminated Polybutadiene
HX	Hydrocarbon X
HYSR	Hybrid Sounding Rocket
ICBM	Intercontinental Ballistic Missile
IPD	Integrated Powerhead Demonstration
IPF	Integrated Processing Facility
ISS	International Space Station
ITAR	International Traffic in Arms Regulations
IWFNA	Inhibited White Fuming Nitric Acid
JAA	Jacksonville Aviation Authority
KLC	Kodiak Launch Complex
KSC	Kennedy Space Center
LAP	Launch Assist Platform
LASR	Large Array of Small Rockets
LC	Launch Complex
LEO	Low Earth Orbit
LOX	Liquid Oxygen
MARS	Mid-Atlantic Regional Spaceport

MDA	Missile Defense Agency
MEMS	Microelectromechanical Systems
MEO	Medium Earth Orbit
MRTFB	Major Range and Test Facility Base
MSFC	Marshall Space Flight Center
MSLV	Microsatellite Launch Vehicle
MTA	Mojave Test Area
NASA	National Aeronautics and Space Administration
NLV	Nanosat Launch Vehicle
NRO	National Reconnaissance Office
O/M	Oxygen-Methane
ONR	Office of Naval Research
ORS	Operationally Responsive Spacelift
OSIDA	Oklahoma Space Industry Development Authority
OSP	Orbital/Suborbital Program
OTV	Orbital Test Vehicle
OV	Orbital Vehicle
PDR	Preliminary Design Review
R&D	Research and Development
RCS	Reaction Control System
RFP	Request for Proposals
RLV	Reusable Launch Vehicle
RP-1	Rocket Propellant 1
RSRM	Reusable Solid Rocket Motor
RSTS	Range Safety and Telemetry System
RTS	Reagan Test Site
SBIR	Small Business Innovation Research
SLC	Space Launch Complex
SLF	Shuttle Landing Facility
SLI	Space Launch Initiative
SLV	Small Launch Vehicle
SSI	Spaceport Systems International
SSME	Space Shuttle Main Engine
SSO	Sun-synchronous Orbit
STEREO	Solar Terrestrial Relations Observatories
STS	Space Transportation System
t/LAD	Trapeze-Lanyard Air Drop
TBD	To Be Determined
TCP/IP	Transmission Control Protocol/Internet Protocol
UAV	Unmanned Aerial Vehicle
ULA	United Launch Alliance
VAB	Vehicle Assembly Building
VAFB	Vandenberg Air Force Base
VAPAK	Vapor Pressurization
VCCW	Vortex Combustion Cold-Wall
VCSFA	Virginia Commercial Space Flight Authority
WAA	Wisconsin Aerospace Authority
WFF	Wallops Flight Facility
WSMR	White Sands Missile Range
XA	eXtreme Altitude

Introduction

The commercial space industry had an active year in 2006 as entrepreneurial space companies built on the progress of previous years. One new commercial launch vehicle, the Falcon 1 developed by Space Exploration Technologies Corporation (SpaceX), debuted, while a suborbital prototype designed by Blue Origin performed its first test flight. The number of U.S. and worldwide commercial orbital launches worldwide increased, and one commercial launch services company, Sea Launch, enjoyed its most productive launch year to date. Against this backdrop, one new commercial spaceport, run by the Oklahoma Space Industry Development Authority (OSIDA), was issued a license by the Federal Aviation Administration (FAA), and other U.S. spaceports continued to make steady progress in their own development plans.

Meanwhile, the emerging space tourism industry continued to lay the groundwork for future operations. Virgin Galactic, the suborbital space tourism venture, cemented its relationship with Spaceport America in New Mexico, while Space Adventures, Ltd. pursued agreements to develop a new fleet of suborbital space tourism vehicles and international commercial spaceports in the United Arab Emirates and Singapore. The fourth—and first female—space tourist journeyed to the International Space Station (ISS). And Genesis Pathfinder 1, an inflatable habitat module developed by Bigelow Aerospace, deployed successfully in orbit, bringing a private space station one step closer to reality.

Finally, commercialization initiatives proceeded apace. The National Aeronautics and Space Administration (NASA) Commercial Orbital Transportation Services (COTS) demonstration program awarded nearly $500 million to two contractors, SpaceX and Rocketplane Kistler, for commercial delivery services to the ISS. The 2006 Wirefly X Prize Cup took place in New Mexico, where private vehicle developers competed for NASA Centennial Challenges and X Prize Foundation awards. And the U.S. Department of Defense (DoD), through a host of initiatives, continued to fund development of new vehicle families able to launch quickly and inexpensively, as well as versatile enough to serve both military and commercial needs.

This report explores these developments and other major events that defined U.S. commercial space transportation in 2006. It showcases current and planned U.S. commercial or commercially-oriented activities. It also addresses reusable launch vehicles (RLVs), space competitions, expendable launch vehicles (ELVs), reentry vehicles and in-space technologies, 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. Readers are encouraged to contact the organizations mentioned in this report for further information on the technologies, programs, and subjects discussed herein.

Space Competitions

In 2004, the Tier 1 (also known as SpaceShipOne) vehicle developed by Scaled Composites staged two consecutive suborbital spaceflights to win the Ansari X Prize competition, demonstrating the effectiveness of a cash prize in stimulating private space vehicle development. Seeking to continue this incentive-based approach, in 2006 the X Prize Foundation organized the Wirefly X Prize Cup at Las Cruces International Airport in New Mexico. Cash awards were offered in three areas as part of the NASA Centennial Challenges Program: the Beam Power Challenge, the Tether Challenge, and the Northrop Grumman Lunar Lander Challenge. Although no contestants fulfilled the criteria necessary to win any of the three challenges, the competition elicited promising technology developments and demonstrated their potential to the general public. Subsequent annual X Prize Cups are planned to encourage further innovation in the personal spaceflight industry, and are expected to feature cash prizes for vehicle developers who achieve milestones such as fastest launch turnaround time, maximum altitude, and fastest speed record.

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.

Expendable Launch Vehicle Industry

In 2006, U.S. commercial orbital launch activity increased relative to the year prior. In 2005, the FAA Office of Commercial Space Transportation (AST) licensed five commercial orbital launches. In 2006, it licensed seven: one Atlas 5, built by Lockheed Martin Corporation and marketed by International Launch Services; one Delta 4, built by The Boeing Company and marketed by Boeing Launch Services; and five Zenit-3SLs, built and marketed by Sea Launch Company, LLC.

Several companies continued to develop new ELV concepts in 2006, including the Alliant Techsystems (ATK) Launch Vehicle developed by ATK; Aquarius by Space Systems/Loral, Eaglet by E'Prime Aerospace; FALCON Small Launch Vehicle (SLV) by Lockheed Martin; Nanosat Launch Vehicle by Garvey Spacecraft Corporation; Eagle SLV by Microcosm; QuickReach by AirLaunch LLC; Z-1 by Zig Aerospace, LLC; and the Zenit-3SLB vehicle being developed by Sea Launch.

Additionally, in 2006 NASA refined plans for the Ares 1 and Ares 5 vehicles, which will leverage Space Shuttle and Apollo-era technologies toward future crewed and uncrewed lunar missions. The agency awarded Ares 1 engine development contracts to ATK Thiokol and Pratt and Whitney. Detailed technical specifications for the Ares 5 vehicle have not yet been announced.

Reusable Launch Vehicle Industry

On March 25, 2006, the partially-reusable SpaceX Falcon 1 vehicle conducted its maiden launch. Although the launch was unsuccessful, the cause of the failure was identified, and SpaceX plans a second launch attempt in 2007.

One other reusable launcher, the New Shepard Reusable Launch System developed by Blue Origin LLC, performed its first test flight on November 13, 2006, under the first-ever experimental permit granted by the FAA.

Additionally, Armadillo Aerospace, a former Ansari X Prize contender, has continued development of a suborbital, piloted spacecraft named Quad. In 2006, a Quad prototype known as "Pixel" flew five demonstration flights at the Wirefly X Prize Cup in pursuit of the Lunar Lander Challenge prize.

Other RLVs under development include the Sea Star Microsatellite Launch Vehicle (MSLV) and the Neptune by Interorbital Systems; the XA 1.0 by Masten Space Systems; the K-1 and Rocketplane XP by Rocketplane Kistler; SpaceShipTwo by The SpaceShip Company, a joint venture between Scaled Composites and Virgin Galactic; Dream Chaser by SpaceDev; Falcon 9 by SpaceX; Altairis by Sprague Astronautics; Michelle-B by TGV Rockets, Inc.; and Xerus by XCOR Aerospace.

Parallel to private RLV development efforts, DoD initiatives such as Operationally Responsive Spacelift (ORS) have resulted in the Affordable Responsive Spacelift (ARES) program. The ARES program was to feature a reusable fly-back lower stage to minimize launch costs. However, Congress eliminated funding for the program in the fiscal year 2007 DoD budget.

Reentry Vehicles and In-Space Technologies

The Vision for Space Exploration, along with the planned 2010 retirement of the Space Shuttle, has prompted the need for new vehicles and technologies to support future crewed and uncrewed missions. In response to these needs, in 2006 NASA selected the prime contractors to develop the Orion crew vehicle (formerly known as the Crew Exploration Vehicle, or CEV) and provide commercial ISS re-supply under the COTS initiative. Lockheed Martin won a seven-year, $4-billion contract to develop the Orion, while SpaceX and Rocketplane Kistler won $278 million and $207 million, respectively, to develop vehicles for potential use as ISS transports under the COTS demonstration program. Additionally, the U.S. Air Force is leading development of the X-37B Orbital Test Vehicle, which will leverage earlier work on the X-37 vehicle program.

Also in 2006, Bigelow Aerospace orbited its first inflatable habitat demonstrator, Genesis Pathfinder 1. The success of the demonstrator, a one-third scale model of the company's planned suborbital habitat, has inspired Bigelow Aerospace to speed up development of a full-scale model that the company hopes to use in ventures such as private orbiting space stations.

Enabling Technologies

Under the joint sponsorship of NASA and the DoD, efforts are underway to develop the Hyper-X series of vehicles featuring supersonic-combustion ramjet (scramjet) motors, as well as a full-flow, hydrogen-fueled, staged combustion rocket engine known as the Integrated Powerhead Demonstrator (IPD). Additionally, a number of private companies are developing cryogenic fuel tanks, in-flight propellant collection systems, advanced liquid-fuel engines, hybrid rocket motors, more sophisticated propulsion systems, enhanced avionics and guidance control systems, new launch techniques such as air launch, and other technologies.

Spaceports

In 2006, federal and non-federal spaceports alike sought to expand their capabilities to entice an emerging orbital and suborbital space vehicles market. One new spaceport, operated by OSIDA, was issued an FAA license to commence commercial operations. Additionally, both Spaceport America in New Mexico and the Blue Origin West Texas Launch Site in Texas staged maiden launches of rockets designed by UP Aerospace and Blue Origin, respectively. One newly planned spaceport, Chugwater Spaceport in Wyoming, emerged after Frontier Astronautics bought a decommissioned Atlas E missile base outside of Chugwater, Wyoming and began to renovate it as a launch site. Another, South Texas Spaceport, completed initial construction of its facilities. Finally, the Jacksonville Aviation Authority (JAA) sought to convert the runway, hangars, and other infrastructure at Cecil Field, Florida for use in a potential commercial spaceport, and began its FAA environmental assessment process in 2006.

Significant 2006 Events

January 10: The U.S. Department of Defense conditionally approves plans by Lockheed Martin Corporation and The Boeing Company to merge their fleets of Evolved Expendable Launch Vehicles (EELVs) into a partnership known as the United Launch Alliance (ULA).

February 15: A Sea Launch Zenit-3SL rocket launches the Echostar X communications satellite from Odyssey platform, Pacific Ocean (154 degrees West, 0 degrees North).

February 16: Space Adventures, Ltd., the space tourism company, announces contracts with the private investment firm Prodea and the Russian Federal Space Agency to develop a fleet of commercial suborbital spaceflight vehicles. Days later, Space Adventures announces plans to develop a $265-million global commercial spaceport at Ras Al-Khaimah, near Dubai in the United Arab Emirates, as well as a similar spaceport in Singapore.

March 7: Rocketplane Limited, Inc. and Kistler Aerospace announce they are merging to form Rocketplane Kistler. The new company plans to develop suborbital and orbital space transportation and cargo vehicles, the first of which is expected to be a version of the K-1 vehicle originally conceived by Kistler Aerospace.

March 25: The maiden launch of the Falcon 1 vehicle, developed by SpaceX, fails 34 seconds into flight. The cause of the failure is later determined to be a fuel leak caused by corrosion of a small aluminum nut that held the fuel pipe fitting in place, which caused the main engine to catch fire. SpaceX plans to stage a second Falcon 1 launch attempt in 2007.

April 12: A Sea Launch Zenit-3SL rocket launches the JCSAT 9 communications satellite from Odyssey platform, Pacific Ocean.

April 20: Lockheed Martin's Atlas 5 rocket launches the Astra 1KR communications satellite from Cape Canaveral Air Force Station (CCAFS).

May 8: Lockheed Martin announces its award of a 20-month, $2.5 million initial contract to study and propose a hybrid launch vehicle for the U.S. Air Force as part of the ORS initiative.

May 24: The Boeing Company's Delta 4 rocket launches the GOES 13 meteorological satellite from CCAFS.

June 18: A Sea Launch Zenit-3SL rocket launches the Galaxy 16 communications satellite from Odyssey platform, Pacific Ocean.

July 4: Shuttle Discovery lifts off from Kennedy Space Center (KSC) carrying supplies and new crew member Thomas Reiter to the ISS aboard the STS 121 mission. The launch marks the second successful Space Shuttle return-to-flight mission since the Shuttle Columbia reentry failure in 2003.

July 12: A Dnepr rocket carries Genesis Pathfinder 1, the first demonstration mission of the inflatable orbital habitat modules developed by Bigelow Aerospace, into orbit. The module inflates successfully.

August 18: NASA selects two companies from six finalists to provide delivery services to the ISS under the COTS initiative. The two companies are Rocketplane Kistler, whose K-1 launch vehicle will be partially funded by NASA with an investment of $207 million, and SpaceX, which will receive $278 million to seed the development and demonstration flight of its Falcon 9 vehicle featuring the Dragon crew and supply capsule.

August 21: A Sea Launch Zenit-3SL rocket launches the Koreasat 5 communications satellite from Odyssey platform, Pacific Ocean.

August 25: In conjunction with U.S. Air Force Space Command, the FAA issues new common federal launch safety standards designed to create consistent, integrated space launch rules for the United States. The standards are designed to enhance public safety by harmonizing safety procedures at facilities nationwide by implementing a formal system of safety checks and balances to identify potential problems before liftoff.

September 9: Shuttle Atlantis, mission STS 115, launches from KSC, marking the third Space Shuttle return-to-flight mission.

September 18: A Soyuz rocket carries the fourth—and first female—space tourist, Anousheh Ansari, to the ISS. Ansari and crew return safely to Earth on September 29.

September 21: Lockheed Martin enters into an agreement with Bigelow Aerospace to explore using human-rated Atlas 5 vehicles to carry passengers to a habitable space complex assembled from Bigelow inflatable modules.

September 25: The Spaceloft XL sounding rocket, designed by UP Aerospace, fails to reach suborbital space on its inaugural flight, instead returning to Earth prematurely following liftoff from Spaceport America in New Mexico.

September 25: The FAA issues the first-ever experimental permit for a reusable suborbital rocket to Blue Origin LLC, the commercial space transportation company founded by Amazon.com CEO Jeff Bezos. The 1-year, renewable permit allows for unmanned vehicle tests to be launched and landed vertically.

October 19-21: Under a second experimental permit issued by the FAA, Armadillo Aerospace conducts five test flights of its Pixel vehicle at the 2006 Wirefly X Prize Cup.

October 30: A Sea Launch Zenit-3SL rocket launches the XM 4 communications satellite from Odyssey platform, Pacific Ocean.

November 8: The newly merged Rocketplane Kistler announces an agreement whereby ATK will become lead contractor for the development, assembly, integration, and testing of the K-1 vehicle.

November 13: Blue Origin stages the first test flight of its suborbital vehicle, Goddard. The flight, launched from the company's West Texas spaceport, lasts about 30 seconds.

November 30: The proposed European small launch vehicle Vega successfully completes a static fire test of its first stage engine. The first launch of the vehicle is planned for 2008.

December 1: Lockheed Martin and Boeing formally complete the United Launch Alliance transaction. The merger, first proposed in May 2005 and finally approved by federal regulators on October 4, 2006, will combine the production, engineering, test, and launch operations for U.S. government launches of Boeing Delta and Lockheed Martin Atlas rockets.

December 9: Shuttle Atlantis, mission STS 116, launches from KSC. The vehicle lands safely on December 22.

December 14: A Delta 2 rocket lifts a classified National Reconnaissance Office (NRO) satellite into orbit in the first launch carried out under the auspices of the United Launch Alliance.

December 15: The FAA issues regulations establishing requirements for crew and passengers involved in private human space flight. The requirements include the provision of safety and risk information from a launch vehicle operator to space flight participants, as well as other requirements for safety measures, training, and general security.

December 16: A Minotaur rocket launches from the Mid-Atlantic Regional Spaceport, successfully orbiting TacSat-2 for the DoD and GeneSat 1 for NASA.

Space Competitions

In the space industry, prize competitions have become an established means for promoting innovative development. Success and popularity of the Ansari X Prize, won in 2004 by Mojave Aerospace Venture's SpaceShipOne, and other technology competitions led to the establishment of major competitive opportunities to increase the level of innovation in governmental and non-governmental space programs. These competitions aim to create available commercial space launch (and other space capabilities) with lower cost, better quality, and more efficient processes than the options currently available. These competitions are an example of enablers of a stronger and more innovative commercial space industry, as is affirmed in the U.S. National Space Policy authorized on August 31, 2006. The three sets of prize competitions currently ongoing are the Wirefly X Prize Cup, America's Space Prize, and the Centennial Challenges program run by NASA.

Wirefly X Prize Cup

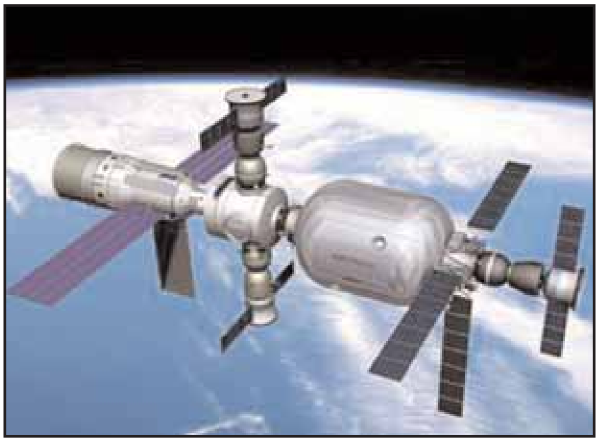
The X Prize Cup is an annual event in New Mexico to advance new concepts and technologies that enable commercial human spaceflight by providing awards and cash prizes. A secondary priority for the competition is to promote education and awareness in the general population about advancements in spaceflight technology. The public has the opportunity to view competitions between providers of commercial space technology and interact with aerospace industry pioneers, who are working to reduce the cost and increase the safety and viability of commercial human space travel. The eventual goal of the event is to have teams compete in several categories of human spaceflight to win the overall X Prize Cup, as well as hold other individual competitions and Rocket Racing League events. Conceptual Cup 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. Current vehicle development timelines may not allow for these types of competitions for several years, though other significant activities will take place at the event.

2006 X Prize Cup

The first official X Prize Cup took place October 20-21, 2006, at Las Cruces International Airport, New Mexico. Three NASA Centennial Challenges competitions were held: the Northrop Grumman Lunar Lander Challenge, Beam Power Challenge, and Tether Challenge. The latter two constituted the event's Space Elevator Games. None of the competitors successfully completed these challenges, but promising technologies were proven in attempts to win the available prize money (see the Centennial Challenges section). Other rocket demonstrations were completed, and static displays provided interactive education for the general public.

Armadillo Aerospace achieved an important milestone for future commercial spaceflight during the event. Armadillo safely carried out the first flight of a vehicle, the "Pixel" Lunar Lander demonstrator, under an FAA-issued experimental permit authorized under the Commercial Space Launch Amendments Act of 2004. Experimental permits allow reusable suborbital launch vehicle developers to flight test vehicle designs without applying for a full commercial launch license.

America's Space Prize



Conceptual design of a completed Bigelow inflatable habitat, to which the America's Space Prize winner could travel

Bigelow Aerospace and its founder, Robert Bigelow, have proposed a commercial spaceflight competition, America's Space Prize, to develop launch vehicles. This prize challenges entities within the United States to design an RLV without government funding, capable of carrying passengers into orbit with the eventual goal of bringing humans to Bigelow Aerospace's inflatable space habitats. According to the rules, competitors will have to build a craft capable of taking a five-person crew 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 of at least five. The vehicle will have to demonstrate the ability to dock with Bigelow's inflatable modules and stay docked for at least 6 months. In addition, no more than 20 percent of the vehicle can consist of expendable hardware. The launch and operations of the Genesis I inflatable module have been successful. For this prize, competitors would use such a module 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's Innovative Partnerships Program Office uses the Centennial Challenges program to advance development of space technologies through prize competitions, bringing important government support to commercial efforts. This program creates specialized competitions to stimulate progress on specific technologies with hopes to further the exploration of space and other NASA missions, using funding outlets beyond the standard procurement process.

Under the terms of a Nonreimbursable Space Act Agreement with NASA, non-profit organizations (called Allied Organizations) administer and execute each of the competitions at no cost to NASA. Seven Centennial Challenges competitions are currently open with participation from U.S, and non-U.S., non-governmental entities. Some of the competitions do not deal directly with commercial space transportation technologies, but all of them spur future space missions that drive the demand for spaceflight.

The Tether and Beam Power Challenges were the first two competitions conducted by the Spaceward Foundation in October 2005. Collectively, the Tether and Beam Power Challenges encourage development of long-term space exploration technologies, including high strength-to-weight materials and high power-density distribution technologies. The $50,000 purses were not won for either of these competitions in 2005, nor did any team win the $200,000 prizes when the competitions were conducted at the X Prize Cup event in 2006. These two competitions will be held annually through 2010, with prize money increasing each year for each of them.

The 2006 X Prize Cup event was also the first opportunity for teams to compete for a total of $2,500,000 in prize purses in the Northrop Grumman Lunar Lander Centennial Challenge. This competition requires teams to repeatedly and successfully fly and land rocket-powered vehicles between landing pads that simulate lunar landing conditions. As was the case in the Tether and Beam Power Challenges, none of the purses were awarded at the first competition event, but teams will be able to compete annually until all the prize money is won.

Despite the fact that the program is still relatively young and no prizes have yet been awarded, NASA has concretely benefited from this highly successful program. The primary goals of the program are being achieved, including the participation of new sources of innovation, the leveraging of taxpayers' dollars, identification of innovative technology development to meet NASA's needs, and an increased awareness of science and technology.

Expendable Launch Vehicles

This survey of U.S. ELVs is divided into four sections. The first reviews the ELVs currently available to serve a wide range of commercial and government payloads. The second 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 third discusses the new launch vehicles being developed exclusively to support the Vision for Space Exploration. The final section reviews suborbital sounding rockets manufactured and operated by U.S. companies.

Current Expendable Launch Vehicle Systems

Table 1, on the next page, lists the ELV systems available in the United States today for commercial, government, or both, missions. The Minotaur is restricted to government payloads, and Boeing is currently marketing the Delta 4 only to government customers. With the 2005 retirement of the Titan 4, all large U.S. government payloads are launched on variants of the Atlas 5 and Delta 4, developed for the EELV program. Atlas 5, Delta 2, Pegasus, and Taurus vehicles are available for commercial and U.S. government launches; the Zenit-3SL is available only to commercial customers.

Atlas 5 – Lockheed Martin Corporation/ULA

Lockheed Martin Commercial Launch Services provides the Atlas 5 launch vehicle family to commercial customers worldwide. Atlas 5 is produced by the ULA, a joint venture of The Boeing Company and Lockheed Martin Corporation. Government launches of the Atlas 5 are provided directly from ULA. The Atlas launch vehicle family traces its roots to the development of the Atlas intercontinental ballistic missile (ICBM) in the 1950s. Today, the Atlas 5 represents the Atlas family, replacing the older Atlas 2 and Atlas 3 vehicles, which were retired in 2004 and 2005, respectively.

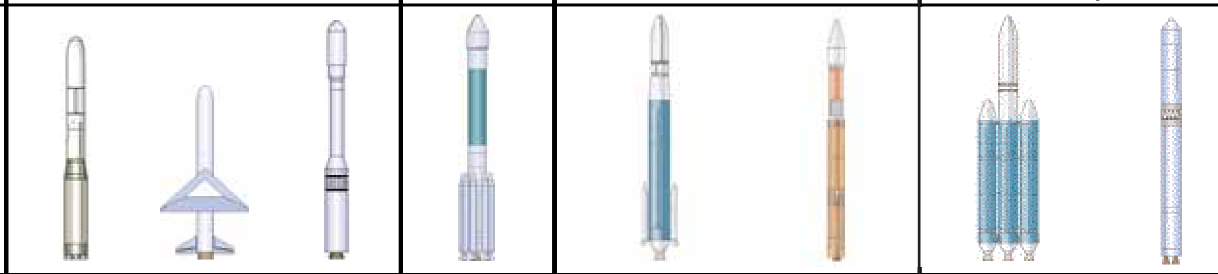
The maiden flight of the Atlas 5 took place on August 21, 2002, when an Atlas 5 401 vehicle successfully launched the Eutelsat Hot Bird 6 spacecraft from CCAFS. Atlas 5 is now Lockheed Martin's sole commercial launch vehicle for the foreseeable future. This family of launch vehicles is based on a common liquid oxygen (LOX)/kerosene first stage design—known as the Common Core Booster™—powered by the NPO Energomash RD-180 engine introduced on the Atlas 3. The second stage of the Atlas may be single or dual engine, with a stretched version of the Centaur upper stage, which was introduced on the Atlas 3B.

Atlas 5

Compared to previous versions, Atlas 5 marks a significant departure in launch preparations. Using a "clean pad" concept at Launch Complex (LC) 41 at CCAFS, the vehicle is prepared for launch "off pad" vertically in the Vertical Integration Facility near the pad. One day before a launch, the fully-prepared vehicle is moved to the pad. Beginning in 2007, the Atlas 5 will also launch from LC-3E at Vandenberg Air Force Base (VAFB), California. Except for the use of the more traditional "stack on pad" concept from the heritage launch vehicle programs, the operating processes used at LC-41 will be employed.

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 April 20, 2006, carrying the Astra 1KR satellite. Additionally, the NASA New Horizons satellite was launched on January 19, 2006. One commercial and five government launches are currently scheduled for 2007.[1]

Table 1: 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/ULA	Boeing/ULA	Lockheed Martin/ULA	Boeing/ULA	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 lb)	440 kg (970 lb)	1,590 kg (3,505 lb)	6,100 kg (13,440 lb)	9,150 kg (20,170 lb) (Delta 4M) 13,360 kg (29,440 lb) (Delta 4M+ (5,4))	12,500 kg (27,560 lb) (Atlas 5-400) 20,520 kg (45,240 lb) (Atlas 5-500)	22,560 kg (49,740 lb)	N/A
Payload Performance (LEO polar)	340 kg (750 lb) (SSO)	190 kg (420 lb) (SSO)	860 kg (2,000 lb) (SSO)	3,600 kg (7,930 lb)	7,510 kg (16,550 lb) (Delta 4 M) 11,300 kg (24,920 lb) (Delta 4M+ (5,4))	N/A	21,140 kg (46,600 lb)	N/A
Payload Performance (GTO)	N/A	N/A	430 kg (950 lb)	2,170 kg (4,790 lb)	4,300 kg (9.480 lb) (Delta 4 M) 7,020 kg (15,470 lb) (Delta 4 M+ (5,4))	4,950 kg (10,910 lb) (Atlas 5-400) 8,670 kg (19,110 lb) (Atlas 5-500)	12,980 kg (28,620 lb)	6,100 kg (13,500 lb)
Launch Sites	VAFB, Wallops	VAFB, Wallops, CCAFS	VAFB	CCAFS, VAFB	CCAFS, VAFB	CCAFS	CCAFS, VAFB	Pacific Ocean

* Atlas 5 launches from VAFB are scheduled to begin in 2007.

Delta 2 – The Boeing Company/ULA

Boeing Launch Services provides the Delta 2 launch vehicle family, produced by ULA, to commercial customers worldwide. Government launches of the Delta 2 are available directly from ULA. The Delta family of launch vehicles traces its heritage to the Thor missile program of the 1950s. Like the Atlas program, the Delta family has undergone a transition prompted by the introduction of the Delta 4 vehicles developed under the EELV program.

Delta 2

The Delta 2 uses a 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 July 7, 2003, with the launch of NASA's Mars

Exploration Rover-B "Opportunity" spacecraft. This vehicle uses larger graphite-epoxy motor (GEM), 46-in diameter strap-on boosters.

The Delta 2 has the capability to launch payloads of 900 to 2,170 kg (1,980 to 4,790 lb) to GTO, and 2,700 to 6,100 kg (5,960 to 13,440 lb) to low Earth orbit (LEO), and can launch from either CCAFS or VAFB. The Delta 2 is expected to remain in service through 2012, primarily launching military and civil government payloads. Six government Delta 2 launches occurred in 2006. As many as four commercial and eight government launches are scheduled in 2007.

Delta 4 – The Boeing Company/ULA

Delta 4

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 United States since the Space Shuttle Main Engine (SSME) 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, the Delta 4 can be configured with two or four solid-fuel strap-on boosters, two upper stage versions, and three payload fairings. This vehicle can 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. The first VAFB launch of a Delta 4, carrying a classified NRO payload, took place on June 27, 2006.[2]

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. United Launch Alliance expects to reduce pad time from 24 days for the Delta 2 to a period of about a week for the Delta 4.

United Launch Alliance 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 were largely intended for government use, but now all five configurations are used for government missions. Payload capacities to LEO range from 9,150 kilograms (20,170 pounds) for the Medium to 22,560 kilograms (49,740 pounds) for the Heavy. Geosynchronous transfer orbit capacities range from 4,300 to 12,980 kilograms (9,480 to 28,620 pounds). Three Delta 4 launches occurred in 2006, including the first from VAFB, and three launches are scheduled in 2007.

Minotaur 1 and 4 – Orbital Sciences Corporation

Minotaur

Under the U.S. Air Force's Orbital/Suborbital Program (OSP), Orbital Sciences Corporation has developed two space launch vehicles as part of the Minotaur family of launch vehicles. The Minotaur 1 was developed by Orbital 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 first two stages of the Minotaur 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. Two Minotaur 1 launches occurred in 2006, including one from the Mid-Atlantic Regional Spaceport (MARS) in Virginia, and two launches are scheduled in 2007.

Orbital Sciences will also operate the Minotaur 4 space launch vehicle, which uses stages from former U.S. Peacekeeper missiles. Minotaur 4 can deliver a larger payload to orbit than the Minotaur 1. It will launch a payload weighing approximately 1,750 kilograms (3,860 pounds) to LEO. The Minotaur 4 is expected to enter service no earlier than 2008.

Pegasus – Orbital Sciences Corporation

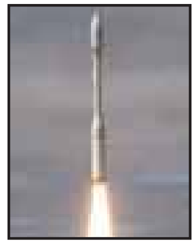
Pegasus XL

Pegasus is an air-launched ELV used to place small payloads into a variety of low Earth orbits. Developed by Orbital Sciences in the late 1980s entirely with private capital, 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 released. (Early Pegasus launches used a B-52 aircraft leased from NASA.) The booster drops for five seconds in a stable horizontal position before igniting its first stage motor and beginning its 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 allows 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 in California; CCAFS and KSC in Florida; NASA Wallops Flight Facility (WFF) in Virginia; Kwajalein Missile Range, Marshall Islands; and Gando Air Force Base (AFB), Canary Islands.

NASA certified Pegasus to carry the highest value satellites (Category Three Certification) because of its demonstrated reliability record. Pegasus has launched its last 23 missions successfully. One Pegasus XL launched in 2006, carrying the three Space Technology 5 microsatellites for NASA. Up to two launches are planned for 2007.

Taurus – Orbital Sciences Corporation



Taurus

The Taurus ELV is a ground-launched vehicle based on the air-launched Pegasus. Orbital Sciences developed the Taurus under the sponsorship of the Defense Advanced Research Projects Agency (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 first stage of the Taurus. The Taurus successfully completed six of seven launch attempts since entering service in 1994. No Taurus launches took place in 2006, none are planned for 2007, and two are scheduled for 2008.

Zenit-3SL – Sea Launch Company, LLC

Zenit-3SL

The Zenit-3SL is a Ukrainian-Russian launch vehicle operated by Sea Launch Company, LLC, a multinational joint venture of four partners. 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. The Boeing Company provides the payload fairing and interfaces, as well as operations and business management.

The Zenit-3SL launches from the Odyssey Launch Platform, which travels from its Sea Launch 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, which is positioned 5 kilometers (3 miles) uprange from the platform during launch operations. While Sea Launch conducts commercial launches with a license from FAA, the multinational nature of the system prevents it from carrying U.S. government payloads. Five successful Zenit-3SL launches took place in 2006, the most to date in a single calendar year; six launches are planned for 2007.

ELV Development Efforts

A number of efforts by both 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.

ALV – Alliant Techsystems

Vehicle: ATK Launch Vehicle	
Developer: Alliant Techsystems	
First Launch: 2007	
Number of Stages: 2	
Payload Performance: 1,360 kg (3,000 lb) suborbital	
Launch Site: MARS	
Markets Served: Responsive launches of small satellites for civil, commercial, and military customers	

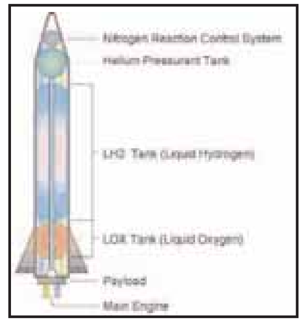
ALV

In October 2006, ATK of Edina, Minnesota, announced it was developing a small launch vehicle, the ATK Launch Vehicle (ALV). The ALV is based on sounding rocket technologies that have been developed by the company. ATK carried out a successful "pathfinder" for the ALV by assembling the vehicle on the pad at MARS in 2006. The first launch of the two-stage ALV, a suborbital flight designated ALV X-1 and carrying two NASA experimental hypersonic and reentry research payloads, is scheduled for 2007 from MARS in Virginia. ATK plans to eventually offer the ALV for government and commercial customers seeking responsive launches of small satellites.[3]

Aquarius – Space Systems/Loral

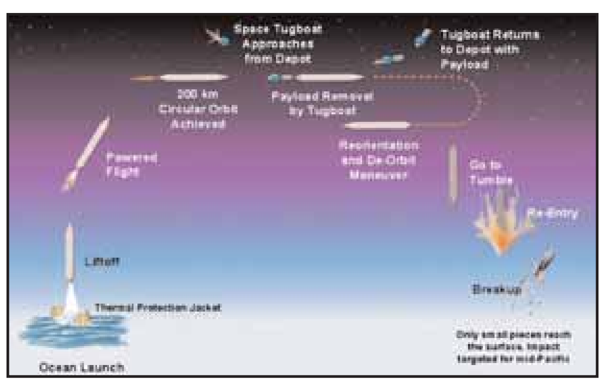
Space Systems/Loral of Palo Alto, California, has proposed Aquarius, a low-cost launch vehicle designed to carry small, inexpensive payloads into LEO. This vehicle is primarily intended to launch inexpensive-to-replace bulk products, such as water, fuel, and other consumables, into space. As currently designed, Aquarius will be a single-stage vehicle 43 meters (141 feet) high and 4 meters (13.1 feet) in diameter, 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. When used for small satellite launch, Aquarius can dispense multiple satellites into nominally 200-kilometer (125-mile) orbits at any desired inclination, as launching at appropriate ocean locations virtually eliminates range constraints on the trajectory. After payload deployment is completed, the vehicle will de-orbit and be destroyed. Planned launch costs are $1-2 million per flight.[4]

Vehicle: Aquarius	
Developer: Space Systems/Loral	
First Launch: TBD	
Number of Stages: 1	
Payload Performance: 1,000 kg (2,200 lb) to LEO (52°)	
Launch Site: TBD	
Markets Served: ISS and spacecraft resupply, small satellite launch	



Aquarius

Previous work on Aquarius includes a study of the launch concept funded by the California Space Authority in 2002. Space Systems/Loral, in conjunction with Aerojet, a GenCorp Company



Aquarius mission profile

based in Sacramento, California, and ORBITEC of Madison, Wisconsin, has performed studies on a vortex combustion cold wall engine, using LOX and liquid hydrogen propellants that would be used on Aquarius. Research on the Aquarius concept includes studies of propellant transfer, analyses of floating launch, and development and testing of an engine with 133,000 to 445,000 newtons (30,000 to 100,000 pounds-force) of thrust. Space Systems/Loral submitted a proposal to NASA for its COTS demonstration program, using Aquarius to send cargo to the ISS, but was not selected to receive funding.[5]

Eagle S-series – E'Prime Aerospace Corporation

Vehicle: Eaglet/Eagle

Developer: E'Prime Aerospace

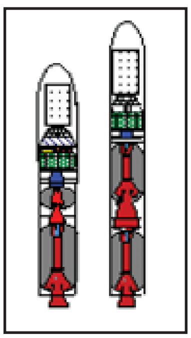
First Launch: TBD

Number of Stages: 2

Payload Performance: 580 kg (1,280 lb) to LEO (Eaglet); 1,360 kg (3,000 lb) to LEO (Eagle)

Launch Site: KSC, WFF, CCAFS, Kodiak

Markets Served: Small satellite launch



Eaglet and Eagle

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 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 propellant 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 U.S. Air Force to use Peacekeeper technology for commercial launch vehicles.

In February 2001, E'Prime signed an agreement with NASA, giving the company use of available property and services on a non-interference basis. For equatorial orbits, E'Prime plans to launch the Eaglet and Eagle, and the company's entire canister launch program from facilities at KSC that the company has yet to construct. Plans to launch from MARS for equatorial orbits and from the Kodiak Launch Complex (KLC) in Alaska for polar orbits are also under consideration. In 2004, the company entered into a partnership with the Department of Energy's Savannah River National Laboratory near Aiken, South Carolina, to develop technologies for the Eagle S-series of launch vehicles and related systems. The company has yet to make appreciable progress in the development of any S-series launch vehicle. In August 2006, Oldham Group, Incorporated, of Tennessee acquired a controlling stake in E'Prime Aerospace for an undisclosed sum.[6]

FALCON SLV – Lockheed Martin Michoud Operations

Vehicle: FALCON SLV

Developer: Lockheed Martin Michoud Operations

First Launch: TBD

Number of Stages: 2

Payload Performance: 840 kg (1,855 lb) to LEO

Launch Site: TBD

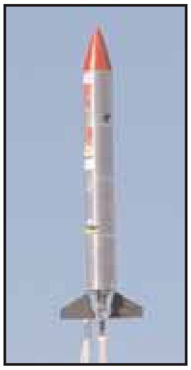
Markets Served: Small satellite launch, responsive space operations

FALCON SLV

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. 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, placing up to 840 kilograms (1,855 pounds) into LEO. In 2005, Lockheed conducted two test firings of the hybrid rocket motor that will be used on the upper stage of the SLV. Though Lockheed did not win a Phase 2B Falcon contract from DARPA in late 2005, the company continues work on the FALCON SLV, focusing on the development and testing of the second stage of the vehicle.[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 lb) to LEO (polar orbit)
Launch Site: TBD
Markets 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) jointly conduct 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. Their current work builds upon flights that the team conducted using several of its LOX/ethanol Prospector research vehicles. The company's most visible accomplishments include the first-ever flight of a composite LOX tank, conducted in partnership with Microcosm, Incorporated; the first-ever powered flights of a liquid-propellant aerospike engine; and the launch and 100 percent recovery of several prototype reusable test vehicles.

In 2006, GSC performed two low-altitude flights of the Prospector 7 (P-7) vehicle, a full-scale NLV prototype that first flew in 2005. The P-7C flight, which took place on April 29, 2006, from the Mojave Desert, carried an experimental Launch Hardware Tracker instrument for the Aerospace Corporation.[8] The P-7D flight, the last for the P-7 vehicle, took place on September 28, 2006, from San Nicholas Island off the coast of Southern California, and was designed to be a pathfinder for responsive launch operations at a remote site. Additional Prospector vehicles are being built for launch in the next few years, with development of the full-scale NLV to follow.[9]

Eagle SLV – Microcosm, Inc.

Vehicle: Eagle SLV
Developer: Microcosm, Inc.
First Launch: TBD
Number of Stages: 3
Payload Performance: 670 kg (1,470 lb) to LEO, 330 kg (730 lb) to SSO
Launch Site: VAFB, WFF, CCAFS
Markets Served: Small satellite launch, responsive space operations


Eagle SLV

Microcosm, Incorporated, of El Segundo, California, has been developing the Scorpius family of ELVs. Several prototypes are under consideration, 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. 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 will have 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 the ability of Scorpius to be ready for flight within eight hours of arrival at the launch pad, using a crew of under 15. 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.

Six orbital variants are planned. The Sprite SLV is projected to loft up to 475 kilograms (1,050 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 deploy payloads to LEO and GTO. The Antares Intermediate-Lift vehicle will 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 2,327 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 had been continuing development of the Scorpius vehicle concept under a separate DoD contract, but that funding ran out in September 2006, forcing Microcosm to suspend work on the project.[10] The company is continuing work on the suborbital SR-M vehicle under a Missile Defense Agency (MDA)/Air Force Research Laboratory (AFRL) contract while it looks for additional funding to restart development of the Sprite SLV.[11]

QuickReach – AirLaunch LLC

Vehicle: QuickReach
Developer: AirLaunch LLC
First Launch: 2009
Number of Stages: 3 (including the launch aircraft)
Payload Performance: 450 kg (1,000 lb) 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-17A or other large cargo aircraft. The rocket is released from the aircraft at an altitude of 7,600 to 10,700 meters (25,000 to 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 a 1-year, $17.8-million contract under Phase 2B of the DARPA/U.S. Air Force Falcon small launch vehicle program in November 2005. During this contract, AirLaunch developed and tested a number of key vehicle subsystems, including the stage separation system and the second-stage engine, and completed an incremental Critical Design Review. Within the last year, AirLaunch performed two drop tests of full-sized replicas of the QuickReach vehicle from C-17 aircraft, including a July 26, 2006, test where the simulated vehicle had the same mass, 32,700 kilograms (72,000 pounds), and length, 20 meters (66 feet), as an actual vehicle.[12] DARPA and the Air Force are expected to make a decision in early 2007 whether to proceed on Phase 2C of the contract. Phase 2 concludes with the test launch of a QuickReach rocket in approximately 2009.

Z-1 – Zig Aerospace, LLC

Vehicle: Z-1
Developer: Zig Aerospace, LLC
First Launch: TBD
Number of Stages: 2
Payload Performance: 5 kg (11 lb) to LEO
Launch Site: TBD
Markets Served: Nanosatellite launch, responsive space operations

Zig Aerospace of King George, Virginia, is developing the Z-1 small launch vehicle. Intended to launch nanosatellites and similar small payloads, Z-1 has a maximum payload capacity of five kilograms (11 pounds) to LEO. The two-stage vehicle, powered by hybrid propellants, is intended to cost less than $200,000 per launch. Zig Aerospace is in the midst of a 3-year development program. Once the Z-1 vehicle enters operations, the company expects to be able to conduct launches as frequently as once a month.[13]

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

Vehicle: Zenit-3SLB
Developer: Space International Services
First Launch: 2007
Number of Stages: 3
Payload Performance: 3,600 kg (7,940 lb) to GTO
Launch Site: Baikonur
Markets Served: Commercial GEO satellite launch

Zenit-3SLB

The Sea Launch Board of Directors voted on September 30, 2003, to offer launch services from the Baikonur Space Center 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. 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 3,600-kilogram (4,410 to 7,940-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; the fairing is the only significant difference between the two vehicles. 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 Intelsat-11 satellite (formerly PAS-11) for Intelsat, is scheduled for 2007. To date, Sea Launch, which manages marketing and sales for this new offering (in addition to its sea-based missions), has received six commercial orders for the Land Launch service.

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, the Crew Launch Vehicle (since renamed the Ares 1) and the Cargo Launch Vehicle (renamed the Ares 5). Both vehicles are designed to leverage Shuttle and even Apollo-era technologies to launch crewed and uncrewed spacecraft required to carry out the Vision for Space Exploration.

Ares 1

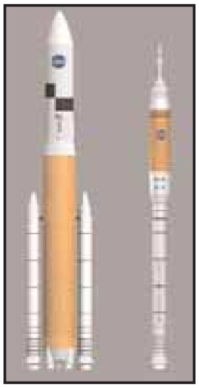
Vehicle: Ares 1
Developer: NASA
First Launch: 2009
Number of Stages: 2
Payload Performance: 22,700 kg (50,000 lb) to LEO
Launch Site: KSC
Markets Served: Crew launches for exploration and possibly ISS missions

The Ares 1 Crew Launch Vehicle is a two-stage vehicle designed principally to launch NASA's Orion CEV into LEO and may also be used to launch cargo spacecraft to the ISS. The first stage of the Ares 1 is a five-segment reusable solid rocket motor (RSRM) derived from the four-segment boosters used in the Space Shuttle program. The second stage is a new design powered by a single J-2X engine (based on the J-2S engine developed at the end of the Apollo program in the early 1970s) using LOX and liquid hydrogen propellants. The Orion spacecraft, along with an escape rocket, will be mounted on top of the second stage.[14]

Development of the Ares 1 is currently in progress. In 2006, NASA awarded contracts to ATK Thiokol to develop the first stage and to Pratt & Whitney Rocketdyne for the J-2X engine. The first test flight of the Ares 1, planned for April 2009, will be a suborbital launch with an inert second stage. The Ares 1 is scheduled to enter service no later than 2014.[15]

Ares 5

Vehicle: Ares 5
Developer: NASA
First Launch: TBD
Number of Stages: 2
Payload Performance: 131,500 kg (290,000 lb) to LEO
Launch Site: KSC
Markets Served: Cargo launches for exploration missions


Ares 5 and Ares 1

The Ares 5 Cargo Launch Vehicle is a two-stage, heavy-lift vehicle that NASA will use to carry out human missions to the Moon and other destinations. The Ares 5 uses two, five-segment RSRMs similar to those developed for the Ares 1 vehicle, attached to either side of a core propulsion stage. The core stage features five RS-68 engines, the same LOX and liquid hydrogen engines as those used currently on the Delta 4 family of vehicles. Under the current exploration architecture, an Ares 5 vehicle would place a lunar module and Earth departure stage into LEO, where the module would dock with an Orion spacecraft launched separately by an Ares 1. The combined vehicle would then leave Earth orbit for the Moon. A detailed development plan for the Ares 5 has not been announced.[16]

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

Over 800 Black Brant rockets have been launched since 1962, when manufacturing 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). Nike, Talos, and Taurus motors used on other Black Brant versions are built in the United States. The launch operator integrates these vehicles. In the United States, NASA has been a frequent user of Black Brant vehicles.


Black Brant

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 of the line, 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 (250-pound) payload to an altitude of at least 1,400 kilometers (870 miles), or a 454-kilogram (1,000-pound) payload to an altitude of at least 400 kilometers (250 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 six to nine 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.

The first Oriole launch took place from NASA WFF on July 7, 2000. That 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 ten-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. A production run of 15 Oriole rockets is scheduled for delivery in late 2007, and one Oriole launch is planned for 2007.

Terrier-Orion – DTI Associates


Terrier-Orion

The Terrier-Orion is a two-stage, spin-stabilized sounding rocket, which 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 (640 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-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. Six Terrier-Orion rockets were launched in 2006 and six are scheduled for launch in 2007.

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-meter (57-foot) long sounding rocket using liquid oxygen and solid fuel, a rubberized compound known as hydroxyl terminated polybutadiene (HTPB). The rocket generated 267,000 newtons (60,000 pounds-force) of thrust during a burn time of 31 seconds, and reached an altitude of approximately 43 miles.

In 2004, further testing of the HYSR motors occurred at NASA Stennis Space Center. These 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 the Royal Norwegian Air Force. The Norwegian company, Nammo Raufoss AS, will build the single-stage rocket. Lockheed Martin-Michoud will provide the design, engineering schematics, and vehicle assembly plan. The hybrid rocket will use liquid oxygen and rubberized HTPB as fuel, have a 31,000-newton (7,000-pound-force) thrust, and have 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.

SpaceLoft XL – UP Aerospace

SpaceLoft XL

UP Aerospace, Incorporated, headquartered in Farmington, Connecticut, with business and engineering offices in Highlands Ranch, Colorado, has developed the SpaceLoft XL sounding rocket for research and commercial applications. The rocket, 6 meters (20 feet) tall and 25 centimeters (10 inches) in diameter, can carry up to 50 kilograms (110 pounds) of payload to an altitude of 225 kilometers (140 miles). A smaller version, the SpaceLoft, can carry 9 kilograms (20 pounds) to an altitude of 130 kilometers (80 miles). UP Aerospace is marketing the SpaceLoft family of vehicles to serve educational and research markets, such as microgravity and atmospheric sciences experiments, as well as commercial applications, including product marketing and novelty promotion.

The first SpaceLoft XL launch, designated SL-1, took place on September 25, 2006, from Spaceport America in New Mexico. However, 9 seconds after launch, at an altitude of 7,300 meters (24,000 feet), the rocket wobbled, deviated from its planned trajectory, and reached a peak altitude of 12,800 meters (42,000 feet) instead of the planned 111 kilometers (69.1 miles).[17] In November 2006, the company finished its comprehensive anomaly investigation and determined the root cause of the flight anomaly to be a high-speed aerodynamic instability. Flight hardware corrective actions have been completed and UP Aerospace plans to carry out its next flight in 2007.[18]

Reusable Launch Vehicles

This section describes active and emerging RLV programs in the United States. Emphasis is placed on vehicles 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. 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 subsection addresses commercial RLV projects underway or in development. The second subsection features government RLV development efforts.

Commercial RLV Development Efforts

Quad – Armadillo Aerospace

Vehicle: Quad

Developer: Armadillo Aerospace

First Launch: 20 October 2006

Number of Stages: 1

Payload Performance: 25 kg (55 lb) to 50 m (165 ft)

Launch Sites: Las Cruces International Airport, New Mexico

Targeted Market: Lunar Lander Challenge competition

Armadillo Aerospace, a former competitor for the Ansari X Prize, is continuing development of suborbital, piloted spacecraft. Recent efforts have focused on a small-scale RLV demonstrator named Quad. This vehicle features a single LOX and ethanol engine, surrounded by four spherical propellant tanks, with electronics and payload boxes on top. Quad is designed to take off and land vertically, but is intended for flights at low altitudes and velocities. Armadillo Aerospace received an experimental permit for the Quad vehicle from the FAA in October 2006.

One Quad vehicle, named Pixel, made five flights during the 2006 Wirefly X Prize Cup at Las Cruces International Airport in New Mexico in an effort to win the Lunar Lander Challenge competition, part of NASA's Centennial Challenges program. The first flight was a vehicle demonstration for the FAA on October 19, prior to the Lunar Lander competition began. On the second flight, on October 20, the vehicle flew the required altitude, distance, and duration, but damaged its landing legs upon landing, preventing a return flight. On its third flight, on the morning of October 21, the vehicle flew normally but landed on the edge of a concrete pad and tipped over. A fourth flight, on the afternoon of October 21, was a success, although one leg buckled on landing. On its final flight at the event, a return trip to win the prize purse, the vehicle tilted seconds after liftoff, triggering an automated shutdown of its engine; the vehicle fell to the ground but was not seriously damaged. Armadillo built a second Quad vehicle, named Texel, but did not fly it at the X Prize Cup.

Quad Lunar Lander vehicle, "Pixel," in flight at 2006 X Prize Cup

Armadillo Aerospace plans to continue development of its Quad vehicles, with the intent to fly them at the 2007 Lunar Lander Challenge competition. The company is also studying a modular vehicle approach, called the Large Array of Small Rockets (LASR), with a single module consisting of two propellant tanks and one engine from the Quad vehicle. A vehicle consisting of four such modules would carry one person to an altitude of 100 kilometers (62 miles).[19]

New Shepard – Blue Origin

Vehicle: New Shepard
Developer: Blue Origin
First Launch: no later than 2010
Number of Stages: 1-2
Payload Performance: 3 people to 100 km (62 mi)
Launch Sites: Culberson County, Texas
Targeted Market: Suborbital space tourism

Blue Origin's Goddard prototype vehicle

Blue Origin is developing the New Shepard Reusable Launch System, a suborbital, vertical-takeoff, vertical-landing RLV for commercial passenger spaceflights. The vehicle will consist of a crew capsule, capable of carrying three or more people, mounted on top of a propulsion module. Engines using high-test peroxide (HTP) and kerosene will power the vehicle. The flights would take place from a private facility operated by Blue Origin in Culberson County, Texas.[20]

As part of the New Shepard development process, Blue Origin plans to build several prototype vehicles, which will be tested and flown from their Texas facility. The first such vehicle, powered by an HTP monopropellant engine, will perform flights to altitudes of about 600 meters (2,000 feet) and lasting no longer than 1 minute. In September 2006, the FAA granted Blue Origin an experimental permit to perform those flight tests. The first permitted launch, by a prototype vehicle named Goddard, occurred on November 13, 2006.[21]

Sea Star – Interorbital Systems

Vehicle: Sea Star MSLV
Developer: Interorbital Systems
First Launch: 4th quarter 2007
Number of Stages: 1.5
Payload Performance: 13 kg (30 lb) to LEO
Launch Sites: Pacific Ocean just west of Los Angeles, California
Targeted Market: Microsatellite launches

Interorbital Systems of Mojave, California, is developing the Sea Star MSLV 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. The engines use an “environmentally friendly” combination of storable hypergolic propellants: inhibited white fuming nitric acid (IWFNA) and “hydrocarbon X” (HX), a company-proprietary fuel. 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. Interorbital Systems plans to begin sounding rocket tests of Sea Star components in 2007, with the first launch scheduled from waters off the California coast in the fourth quarter of 2007.[22]

Neptune – Interorbital Systems

Vehicle: Neptune
Developer: Interorbital Systems
First Launch: late 2008/early 2009
Number of Stages: 1.5
Payload Performance: 4,500 kg (10,000 lb) to LEO
Launch Sites: Pacific Ocean just west of Los Angeles, California
Targeted Market: Orbital space tourism

Neptune

Neptune is a scaled-up version of Interorbital Systems' 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. These engines are larger versions of the one 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. The first launch is planned for late 2008 or 2009 off the California coast.

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 tanks of the module, spheres 6 meters (20 feet) in diameter, would be purged of any remaining propellant, then pressurized to serve as habitation modules. The company has built a full-sized, six-person crew module 5.2 meters (17 feet) in diameter and outfitted it for crew and passenger training at its Mojave, California, facility.[23]

XA 1.0 – Masten Space Systems

Vehicle: XA 1.0
Developer: Masten Space Systems
First Launch: 2008
Number of Stages: 1
Payload Performance: 100 kg (220 lb) to 100 km (62 mi)
Launch Sites: TBD
Targeted Market: Suborbital research payloads

Masten Space Systems of Mojave, California, is developing the eXtreme Altitude (XA) series of suborbital RLVs, initially designed to carry small research payloads. The first in the series, the XA 1.0, is a vertical-takeoff, vertical-landing vehicle powered by LOX and isopropyl alcohol engines. The XA 1.0 is designed to carry a 100-kilogram (220-pound) payload to an altitude of at least 100 kilometers (62 miles), performing several such flights per day at a cost per flight of $20,000 to $30,000. The company is selling payload space on the vehicle for as little as $99 for a 350-gram (12-ounce) "CanSat." Beyond the XA 1.0, the company has proposed the XA 1.5, which could carry a 200-kilogram (440-pound) payload to 500 kilometers (310 miles), and the XA 2.0, which would be able to carry 2,000 kilograms (4,400 pounds) or five people to 500 kilometers.

XA 1.0

As part of the development of the XA 1.0, Masten is building several prototype vehicles. The first, the XA 0.1, is scheduled to begin flight tests in 2007. Larger prototypes, XA 0.2 and XA 0.3, may also be flown in the 2007 Lunar Lander Challenge at the X Prize Cup in New Mexico.

K-1 – Rocketplane Kistler

Vehicle: K-1
Developer: Rocketplane Kistler
First Launch: Late 2008
Number of Stages: 2
Payload Performance: 5,700 kg (12,500 lb) to LEO
Launch Sites: Woomera, Australia; U.S. site TBD
Targeted Market: ISS crew and cargo resupply, satellite launch, orbital space tourism

K-1

Rocketplane Kistler, the company formed in March 2006 by the merger of Rocketplane Ltd. and Kistler Aerospace Corporation, is actively developing the K-1 orbital RLV. The K-1, whose design dates back to the mid-1990s, is a two-stage RLV capable of placing up to 5,700 kilograms (12,500 pounds) into LEO. Originally developed primarily to launch satellites into LEO and other orbits, the K-1 is now being developed to serve the ISS cargo and crew resupply market as well as satellite launch and other applications.

The K-1 employs off-the-shelf technology and components in its design. Three LOX and kerosene GenCorp Aerojet AJ26-58/-59 engines, capable of generating 4.54 million newtons (1.02 million pounds-force) of thrust, power the Launch Assist Platform (LAP) or first stage. These engines are U.S. modifications of the fully developed, extensively tested core of the NK-33/NK-43 engines, 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 (OV), continues into LEO, powered by a single Aerojet AJ26-60 engine with a thrust of 1.76 million newtons (395,000 pounds-force). At the end of its mission, a LOX and ethanol thruster performs a deorbit burn. The OV lands near the launch site using a parachute and airbag combination similar to the LAP.

Rocketplane Kistler expects to operate the K-1 from two launch sites: Spaceport Woomera in South Australia and a site in the United States yet to be determined. Kistler Aerospace received authorization from the Australian government to begin construction of launch facilities in April 1998 and held a groundbreaking ceremony at the site several months later. The launch pad design is complete, and Rocketplane Kistler will conduct its initial K-1 flights and commercial operations from Woomera. In 1998, Kistler Aerospace signed an agreement with the Nevada Test Site Development Corporation to permit Kistler to occupy a segment of the U.S. Department of Energy, Nevada Test Site, for its launch operations. The FAA environmental review process was completed for the project in 2002. The company is currently examining other options for a domestic launch site, including CCAFS.

Development of the K-1 had been suspended for several years, dating back to when Kistler Aerospace filed for reorganization under Chapter 11 of the U.S. Bankruptcy Code in 2003. At that time, the first K-1 vehicle was 75 percent complete. After the merger, Rocketplane Kistler submitted a proposal to NASA for the COTS demonstration program, proposing to use the K-1 to transport cargo and crews to and from the ISS. In August 2006, NASA selected Rocketplane Kistler as one of the two companies to receive COTS awards, with Rocketplane Kistler receiving $207 million.[24] Rocketplane Kistler had originally teamed with Orbital Sciences Corporation to restart work on the K-1, but Orbital backed out of the agreement in September 2006. The company has since signed agreements with Andrews Space, Incorporated, and ATK to manage development of the K-1. As part of the COTS award, Rocketplane Kistler will carry out two test flights of the K-1 in late 2008 and early 2009. In addition to ISS resupply, Rocketplane Kistler is looking at other markets that could be served by the K-1, including orbital space tourism and support for the DoD Operationally Responsive Space program.

Rocketplane XP – Rocketplane Kistler

Vehicle: Rocketplane XP

Developer: Rocketplane Kistler

First Launch: Late 2008

Number of Stages: 1

Payload Performance: 450 kg (950 lb) to 100 km (62 mi)

Launch Sites: Oklahoma Spaceport

Targeted Market: Suborbital space tourism, microgravity research

Rocketplane Kistler is continuing development of the Rocketplane XP suborbital RLV. Capable of 160,000 newtons (36,000 pounds-force) of thrust, the Rocketplane XP is a four-seat vehicle based on a Learjet, powered by two jet engines and one Polaris Propulsion AR-36 LOX and kerosene rocket engine. The Rocketplane XP would take off from an airport under jet power, fly to an altitude of 9,100 to 12,200 meters (30,000 to 40,000 feet), then ignite its rocket engine for a 70-second burn, carrying the vehicle to an altitude of at least 100 kilometers (62 miles). The vehicle would then fly back to land, either under jet power or unpowered, at the same site as takeoff.

Rocketplane XP

In January 2006, Rocketplane Ltd. signed a Space Act Agreement with NASA's Johnson Space Center, whereby NASA will loan the company a Rocketdyne RS-88 engine. Rocketplane Kistler may use the RS-88 for both ground tests and a series of flight tests until the AR-36 engine is ready.[25] As of August 2006 the first XP vehicle was 30 percent complete and scheduled to begin flight tests in 2009 at the Oklahoma Spaceport.

Since 2004, Rocketplane Ltd. has signed a series of marketing agreements to sell suborbital tourist flights. The company is currently taking reservations for Rocketplane flights and hopes to make its first tourist flight in 2009. As currently envisioned, the spaceflight experience would include 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.

SpaceShipTwo – Scaled Composites, LLC/Virgin Galactic

Vehicle: SpaceShipTwo

Developer: Scaled Composites

First Launch: 2008

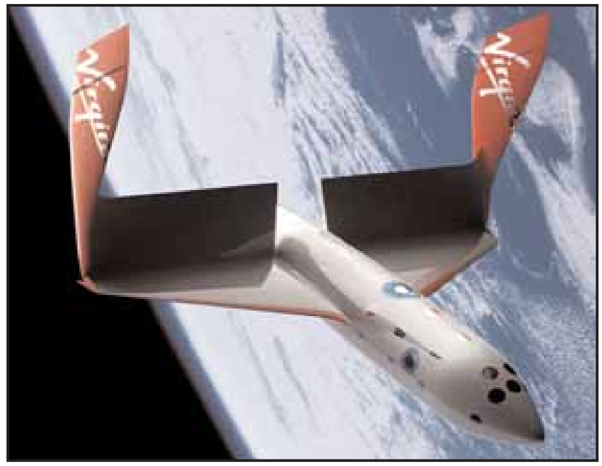
Number of Stages: 2

Payload Performance: 8 people to minimum of 100 km (62 mi)

Launch Sites: Mojave Air and Space Port, Spaceport America

Targeted Market: Suborbital space tourism

Scaled Composites, LLC, and Virgin Galactic, a subsidiary of the Virgin Group of Companies, announced the formation of a joint venture, called The Spaceship Company, in July 2005. The purpose of The Spaceship Company is to oversee development and production of SpaceShipTwo, a commercial suborbital spacecraft based on technology developed for SpaceShipOne. The Spaceship Company will produce the first five SpaceShipTwo vehicles for Virgin Galactic, which plans to put them into commercial service offering suborbital space tourism flights possibly starting in 2009. The venture will also develop a carrier aircraft, WhiteKnightTwo, that will be used to air-launch SpaceShipTwo in much the same manner that the original White Knight aircraft air-launched SpaceShipOne.



SpaceShipTwo

In September 2006, Virgin Galactic unveiled a mockup of the interior of SpaceShipTwo at a technology exposition in New York City. The vehicle will accommodate two pilots and six passengers and feature reconfigurable seats, so passengers are properly positioned to withstand the g-forces encountered during launch and reentry. Flight tests of the SpaceShipTwo and WhiteKnightTwo vehicles will commence during 2008.[26] Virgin Galactic estimates the total cost of developing and testing SpaceShipTwo, as well as developing facilities to accommodate the vehicle at Mojave Air and Space Port and Spaceport America, will be $225 to $250 million.[27]

Dream Chaser – SpaceDev

Vehicle: Dream Chaser

Developer: SpaceDev

First Launch: 2009

Number of Stages: 2 for suborbital, 4 for orbital

Payload Performance: 6 people

Launch Sites: TBD

Targeted Market: Suborbital space tourism, ISS crew and cargo resupply

Dream Chaser is an RLV under development by SpaceDev to serve suborbital and orbital applications. The design of this vehicle 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 8.8 meters (29 feet) and wingspan of 7.2 meters (23.5 feet) of the HL-20, but it decreases the number of passengers from 10 to 6 and reduces the

Dream Chaser

mass to below 10,000 kilograms (22,000 pounds). For suborbital flights, the vehicle will launch vertically, using hybrid engines. On orbital flights, the vehicle will launch on top of hybrid boosters or existing launch vehicles. In both scenarios, the vehicle will glide to a runway landing.

SpaceDev was a finalist for NASA's COTS demonstration program to fund the development of commercial vehicles to service the ISS, but was not selected to receive an award. In September 2006, Benson Space Company, a new space tourism venture established by SpaceDev founder Jim Benson, announced that it had submitted a request for proposals to SpaceDev for the development of the suborbital version of Dream Chaser. Benson Space Company plans to eventually enter into a contract to fund the development of the suborbital Dream Chaser model and will operate those vehicles from locations to be determined.[28]

Falcon 1 – Space Exploration Technologies Corporation

Vehicle: Falcon 1

Developer: Space Exploration Technologies Corporation

First Launch: 2006

Number of Stages: 2

Payload Performance: 705 kg (1,555 lb) to LEO

Launch Sites: Kwajalein Atoll, VAFB

Targeted Market: Small satellite launch

SpaceX of El Segundo, California, is developing the partially reusable Falcon 1 launch vehicle, that can place up to 705 kilograms (1,555 pounds) into LEO for about $7 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. SpaceX privately developed the entire two-stage vehicle from the ground up, including the engines, cryogenic tank structure, and guidance system. The first stage engine, known as Merlin, uses pump-driven LOX and kerosene. The second stage engine, called Kestrel, uses a pressure-fed LOX and kerosene system.

Falcon 1

The first Falcon 1 launch took place on March 24, 2006, from Omelek Island in the Kwajalein Atoll in the Pacific Ocean, with the FalconSat-2 micro-satellite built by the U.S. Air Force Academy as its payload. However, the Merlin engine prematurely shut down shortly after liftoff, causing the vehicle to impact a short distance from the launch pad. An investigation determined that a corroded aluminum nut on a fuel pump inlet allowed kerosene to leak; the fuel ignited and caused a loss of pneumatic pressure, closing the propellant valves for the engine 34 seconds after liftoff. DARPA cleared the vehicle to return to flight in July 2006. The next launch, a demonstration flight carrying two experimental payloads, including a low-cost satellite communications transceiver and an autonomous flight safety system, is planned for early 2007.[29]

Falcon 9 – Space Exploration Technologies Corporation

Vehicle: Falcon 9

Developer: Space Exploration Technologies Corporation

First Launch: First quarter 2008

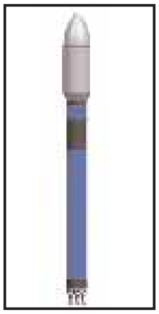
Number of Stages: 2

Payload Performance: Up to 28,400 kg (62,620 lb) to LEO, 12,450 kg (27,450 lb) to GTO

Launch Sites: Kwajalein Atoll, VAFB

Targeted Market: Launch of medium and large satellites, ISS crew and cargo resupply

Announced by SpaceX in September 2005, the Falcon 9 is the company's newest and largest launch vehicle. The Falcon 9 vehicle is based on much of the same technology as the Falcon 1. The Falcon 9 features nine Merlin engines in its first stage with engine-out capability to enhance reliability. The second stage will use one Merlin engine.


Falcon 9

Falcon 9 vehicles can be configured in a variety of ways to serve a broad market. Falcon 9 can place up to 10,350 kilograms (22,820 pounds) into LEO and 4,550 kilograms (10,030 pounds) into GTO. Multiple manifest/half bay missions on Falcon 9 will be available to serve medium-size payloads in place of the Falcon 5, a smaller vehicle the company no longer plans to develop. The Falcon 9 Heavy (comparable to the Delta 4 Heavy) features three common booster cores similar to the Falcon 9 first stage with nine Merlin engines each. This version can carry up to 28,400 kilograms (62,620 pounds) to LEO and 12,450 kilograms (27,420 pounds) to GTO.

Launch costs for the Falcon 9 range from $27 million for the medium version to $78 million for the heavy, in 2006 dollars. Both stages are intended to be recovered and reused, although the ability to reuse the stages is not factored into the current launch cost.

The first Falcon 9 launch, for a U.S. government customer, is scheduled for the first half of 2008. Other customers include MacDonald, Dettwiler and Associates Ltd. of Canada and Bigelow Aerospace. In August 2006, SpaceX won a COTS demonstration award from NASA with a maximum value of $278 million. Under terms of the award, SpaceX will perform three Falcon 9 launches of its Dragon reusable spacecraft in late 2008 and early 2009 to demonstrate its ability to ferry cargo to and from the ISS.[30]

Altairis – Sprague Astronautics

Vehicle: Altairis

Developer: Sprague Astronautics

First Launch: mid-2008

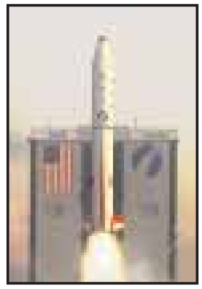
Number of Stages: 1

Payload Performance: 7 people to 120 km (75 mi)

Launch Sites: CCAFS

Targeted Market: Suborbital space tourism, space launch booster stage

Sprague Astronautics (formerly AeraSpaceTours) is developing Altairis, a rocket using RP-1 and LOX propulsion. Altairis will launch vertically and have the ability to carry seven passengers to space. In 2005, the company signed a Commercial Space Operations Support Agreement with the U.S. Air Force. This agreement ascertains the ground rules intended for proposed access of the launch facilities and support services at CCAFS. The agreement is effective for five years and renewable thereafter. Sprague Astronautics plans to begin flights of the Altairis in mid-2008.


Altairis

Michelle-B – TGV Rockets, Inc.

Vehicle: Michelle-B

Developer: TGV Rockets

First Launch: TBD

Number of Stages: 1

Payload Performance: 1,000 kg (2,200 lb) to 100 km (62 mi)

Launch Sites: TBD

Targeted Market: Remote sensing, science, including microgravity research; national security applications


Michelle-B

TGV Rockets, Inc. (TGV) is developing Michelle-B, a fully reusable, remotely-piloted suborbital vehicle, designed to carry up to 1,000 kilograms (2,200 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 and kerosene engines for use on 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. The company has completed a preliminary design review of the Michelle-B and is currently working on risk reduction activities for vehicle subsystems.

Xerus – XCOR Aerospace

Vehicle: Xerus

Developer: XCOR Aerospace

First Launch: TBD

Number of Stages: 1

Payload Performance: 10 kg (22 lb) to LEO

Launch Sites: Mojave Air and Space Port

Targeted Market: Suborbital space tourism, nanosatellite launch, microgravity research

Xerus

In July 2002, XCOR Aerospace announced plans to develop a suborbital RLV, named Xerus. The Xerus would take off horizontally from a runway under rocket power and fly to an altitude of 100 kilometers (62 miles) before returning for a runway landing. XCOR plans to use Xerus for 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.

In April 2004, XCOR Aerospace received a license from the FAA to perform flights of an intermediate demonstration vehicle, called Sphinx, from Mojave Air and Space Port. That license expired at the end of 2006 without any flights having taken place. XCOR continues fundraising and technical development for the vehicle and anticipates filing a new license application for it when ready.[31]

Government RLV Development Efforts

Throughout the 1980s and 1990s, the DoD and NASA 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. However, none of these concepts resulted in a fully operational vehicle. In recent years, these technology development efforts diminished. The U.S. Department of Defense focused on operating its large EELV vehicles and developing small responsive launch vehicles. At the same time, NASA shifted its emphasis to developing large ELVs designed to implement the Vision for Space Exploration. Little government activity in RLV development is anticipated for the foreseeable future.

Space Shuttle

Vehicles: Atlantis, Discovery, 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 1981

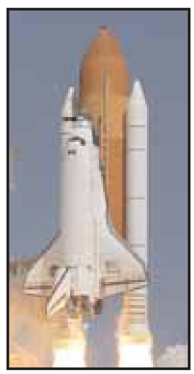
Number of Stages: 1.5

Payload Performance: 24,900 kg (54,890 lb) to LEO

Launch Sites: KSC

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 117 launches since its introduction in 1981.



Space Shuttle

The three remaining orbiters—Atlantis, Discovery, and Endeavour—were grounded after the complete destruction of the Space Shuttle Columbia, which disintegrated over Texas on February 1, 2003, during reentry into the Earth's atmosphere. 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 external tank during launch led NASA to delay future Shuttle launches until the issue was resolved. Flights resumed with the launch of Discovery on mission STS-121 on July 4, 2006. Today, the Space Shuttle is the only available means 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.

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 through the end of fiscal year 2006. In October 2006, NASA awarded the joint venture a 6-month letter contract, valued at $1.1 billion, as the first part of a 4-year contract that will continue Shuttle operations through the retirement of the fleet at the end of fiscal year 2010.[32]

Affordable Responsive Spacelift

The U.S. Air Force recently investigated the development of a partially reusable launch system under the ARES program. As 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 to 48 hours) at a lower cost than purely expendable or reusable systems. The U.S. Air Force started early phase concept studies in 2005, including development of a subscale demonstrator that could launch small payloads into orbit. However, Congress eliminated funding for the ARES program in the fiscal year 2007 DoD budget.

Reentry Vehicles and In-Space Technology

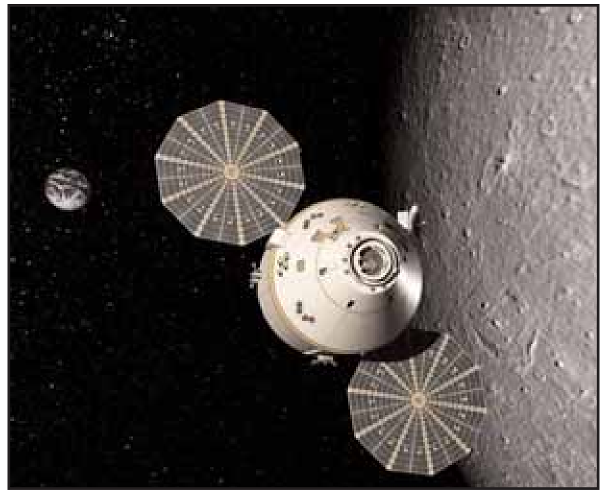
The Vision for Space Exploration has spurred the design and development of new vehicles and technologies for future crewed and uncrewed spaceflight missions. Two vehicle contractor competitions were completed during 2006, with NASA selecting prime commercial contractors to develop the Orion crew vehicle and commercial ISS crew and cargo demonstrators.

There are other development efforts ongoing to create new orbital and reentry capabilities. The U.S. Air Force is developing the X-37B Orbital Test Vehicle to perform military missions in orbit. Commercial in-space technologies are also being developed without the financial support of the U.S. government, in particular Bigelow Aerospace's inflatable space habitats.

Orion Crew Vehicle

Lockheed Martin is the prime contractor for the Orion crew vehicle, previously designated as the CEV, under NASA's Constellation Program for future exploration. NASA announced the prime contractor selection on August 31, 2006. NASA opted for Lockheed Martin's design over that of a Northrop Grumman-Boeing team and awarded an initial seven-year base contract worth just under $4 billion. The contract contains an option worth another $4 billion for production and operational engineering activity up to 2019. Lockheed Martin's contracting team includes Honeywell, Orbital Sciences, United Space Alliance, and Hamilton Sundstrand. NASA began work with the two semi-finalist contracting teams in July 2005 after down-selecting from eight initial concepts that were originally submitted for this vehicle.

Once the Shuttle is retired, Orion will be used to transport crew for exploration missions, initially to LEO and later to the Moon, Mars, and beyond. The spacecraft will consist of a combined pressurized crew module and service module, launched into orbit by the planned Ares 1 Crew Launch Vehicle. The current Orion design has the capacity to transport six crew members to the ISS, if necessary, and four people on missions to the Moon. The first flight of Orion carrying humans is to occur no later than 2014, and the first flight to the Moon is planned for no later than 2020.



Orion CEV

The spacecraft's conical shape is similar to the capsules predating the Shuttle, but Orion will contain state-of-the-art technologies provided by the contracting team and NASA, including but not limited to systems for launch abort, reentry using new thermal protection technology, and ground landing. In addition, Orion's 5-meter (16.5-foot) diameter will allow for more than twice the volume—doubling crew capacity and increasing interior space—of Apollo-era modules.

International Space Station Crew and Cargo Transport

The decision to finish constructing the ISS by the end of the decade and maintain its operation with a six-person crew reinforces the demand for continual transport flights to and from the station. Several government systems to fulfill this demand are either operational or planned. The Shuttle will be the primary American system for bringing new station components, crew, and cargo to the ISS until its retirement. Russia's crewed Soyuz and Progress cargo vehicles are current robust international systems for replenishing the station. Additional international capacity is planned, including the Japanese H-2 Transfer Vehicle and European Automated Transfer Vehicle that are both currently in the development stage.

American commercial vehicles are planned to supplement these government systems for the missions of crew and cargo transport to the ISS in the future. On August 16, 2006, NASA announced the signing of two Space Act Agreements, under the COTS demonstration program, with American companies to develop and demonstrate the ability to provide transportation services to the ISS. The companies, Rocketplane Kistler and SpaceX, will each build an orbital vehicle to prove the necessary transport capabilities under Phase 1 of the agreement, which calls for three vehicle flights before 2010. The concepts will demonstrate a combination of pressurized and unpressurized cargo delivery, disposal, and return, as well as the option for crew transport. Fixed payments will be made to the companies as they achieve milestones for design and development. Phase 2, a separate contracting opportunity from Phase 1, will consist of a competitive procurement of cargo services to the ISS with an option for crew services. In addition to the COTS agreements, the companies plan to provide their vehicles for other commercial and government markets.

Rocketplane Kistler K-1

K-1

The two-stage K-1 vehicle is Rocketplane Kistler's design for providing crew and cargo services for NASA, as well as performing missions for other customers. The design calls for a fully reusable system that will take off vertically and return to Earth landing on ground. The K-1 will utilize two spaceports: first the Woomera Spaceport in Australia and, second, a spaceport in the United States. A test flight of the vehicle is planned for early 2009. The crewed version of the vehicle will carry up to five people accommodated in approximately 30 cubic meters (1,070 cubic feet) of interior space.

Rocketplane Kistler has assembled a diverse contracting team to provide mission critical hardware and services. The team has a large amount of hardware already available as a result of previous work completed by Kistler Aerospace on the K-1 design. NASA's COTS program has called for $207 million for K-1 milestone payments, and private funding will supplement this investment.

SpaceX Dragon


Dragon

SpaceX is developing the Dragon orbital vehicle for NASA's COTS program and for other future space transportation missions. This module will launch vertically on top of SpaceX's Falcon 9 vehicle. The Dragon will land in the waters near the launch site. The first test flight of this module is planned for 2008, with subsequent launches over the following year and later into the future. Notably, the first launch of the Dragon module is not forecasted to be the first launch of the Falcon 9 rocket. The structural design of Dragon will be identical for cargo and crew missions, providing a capacity of about three metric tons (3.3 tons) for launch and return in either configuration. The vehicle crew capacity is planned for up to seven people.

Private funding for Dragon will be supplemented with NASA COTS funding through a Space Act Agreement, as the company achieves vehicle milestones. The current plan for NASA funding includes $278 million, which could change as the demonstration process continues. SpaceX has successfully assembled a team to assist in providing support for the demonstrations.

X-37B Orbital Test Vehicle

U.S. Air Force, Rapid Capabilities Office, is leading development of an unmanned reusable space vehicle designated the X-37B Orbital Test Vehicle (OTV). To support long-term goals in space, this new capability will serve as a platform for science and technology demonstration and testing. Experiments will be carried in a payload bay, which can open and expose its contents to the space environment, similar to the bay in the Space Shuttle. This vehicle leverages previous work NASA, DARPA, AFRL, and Boeing completed for the X-37 program. As it was for the original X-37 vehicle, Boeing is the prime contractor for the OTV.

The OTV will launch vertically into orbit on an expendable rocket and have the ability to deorbit on command and land horizontally for reuse. Initial plans call for launching the first OTV from CCAFS on an Atlas 5 in early 2008. The vehicle will then deorbit and land on a runway at either VAFB or EAFB in California. The first flights will be used for vehicle testing, after which operational technology experiment flights will be conducted.

Bigelow Aerospace

Bigelow Genesis 1

Bigelow Aerospace successfully launched, deployed, and is currently maintaining its first orbital expandable habitat demonstrator, called Genesis-1. Genesis-1 was launched on an ISC Kosmotras Dnepr rocket on July 12, 2006. The approximately 1/3-scale demonstrator reached its targeted low-Earth orbit, deployed its solar arrays, and successfully pressurized, proving the fidelity of the expandable habitat design. The Genesis-1 continues to transmit telemetry and vital data to Bigelow's mission control center located in North Las Vegas, Nevada. The Genesis-1 spacecraft has a usable volume of 11.5 cubic meters (410 cubic feet) and has an anticipated orbital lifespan of between three and thirteen years. The flight of Genesis-1 was the first in a series of technical demonstrators that Bigelow plans to launch, eventually culminating in the deployment of its first, full-scale, human habitable spacecraft.

Bigelow Aerospace is preparing to place a second demonstrator, Genesis-2, into orbit in the first or second quarter of 2007 using another ISC Kosmotras Dnepr launch vehicle. This spacecraft will continue the company's testing and validation campaign for its expandable habitats and will again be launched from a recently commissioned launch site near the town of Yasny, in the Orenburg Region of the Russian Federation.

Due to the success of Genesis-1, Bigelow Aerospace has expedited its future development schedule and, after the potential launch of a final sub-scale demonstrator in 2008, the company will proceed to develop and deploy the "Sundancer," Bigelow's first spacecraft capable of supporting a human crew. The Sundancer may launch at some point during the 2010–2011 time period and should be able to sustain a crew of three. Crew and cargo will travel to the Sundancer on a yet to be determined launch vehicle, although it is publicly known that Bigelow Aerospace is having conversations with numerous potential launch providers including SpaceX, Lockheed Martin, and several others, in addition to providing the "America's Space Prize" space transportation competition.

Enabling Technologies

Several efforts are underway to develop enabling technologies for ELVs and RLVs. These efforts include government-sponsored and commercial research projects in the areas of avionics, air launch technologies, composite cryogenic fuel tanks, automated composite technologies, and propulsion systems. The majority of these development programs focus 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, 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, Microelectromechanical Systems (MEMS) gyroscopes, 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.[33]

During 2006, Microcosm continued its collaborative efforts on the plug-and-play data network system for launch vehicles and satellite avionics with the AFRL Vehicle Directorate in Albuquerque.[34] Since February, Microcosm and AFRL have also started working on a plug-and-play interface for an inertial measurement unit for spacecraft.

In May 2005, SpaceDev initiated development of standardized and miniaturized avionics for small launch vehicles under an AFRL Small Business Innovation Research (SBIR) contract. The goal is to substantially reduce the mass and cost of flight avionics while enhancing their scalability and reliability.[35]

Air Launch Method – Transformational Space Corporation

Transformational Space Corporation (t/Space) successfully drop-tested several 23 percent dummy boosters over the Mojave Desert in 2005 using Scaled Composites's Proteus aircraft to test a new air launch method known as "Trapeze-Lanyard Air Drop," or "t/LAD." During 2006, the flying qualities of a full-size carrier aircraft and booster stack conducting t/LAD releases were evaluated using a NASA Ames six-degrees-of-freedom flight simulator. The t/LAD approach employs an innovative technique that causes a dropped booster to rotate toward vertical without requiring wings. This approach allows an aft-crossing trajectory in which the rocket crosses behind the carrier aircraft, greatly enhancing safety.

t/LAD launch method

The innovation developed by t/Space is a new mechanism that holds onto 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 nozzle of the rocket ensures the rotation happens slowly. This approach improves the simplicity, safety, cost, and reliability of launching people into LEO.[36]

Air Launch Method – AirLaunch LLC

AirLaunch Dummy Booster air drop from C-17A plane

In July 2006, AirLaunch LLC demonstrated the safe release of a dummy rocket from an Air Force C-17 cargo airplane. A full-scale simulated AirLaunch QuickReach rocket, weighing almost 32,660 kilograms (72,000 pounds) and measuring 20 meters (65.8 feet) in length, was dropped as part of the DARPA/Air Force FALCON SLV Program. The unmodified C-17A aircraft released the test article at an airspeed of 600 kilometers/hour (330 knots) from an altitude of 9,700 meters (32,000 feet). The drop was third in a series of envelope expansion tests to verify the ability of the C-17 to safely deliver AirLaunch's full-scale, full-weight QuickReach™ rocket to its operational launch altitude. Previous tests took place in June 2006 and in September 2005. Each test set a new C-17 record for the longest and heaviest single item dropped from the aircraft.[37] The initial test in 2005 demonstrated the QuickReach™ release technology, including proof that the nose of the booster does not hit the roof of the C-17A airplane as the rocket leaves the carrier aircraft.

The AirLaunch approach improves upon previous air-release methods, such as the 1974 Minuteman missile air launch demonstrator, 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, and only the booster leaves the carrier aircraft—no pallets fall into the ocean or on to land.

AirLaunch achieves responsiveness by launching the rocket at altitude from an unmodified C-17A airplane or other cargo aircraft. This approach avoids delays caused by 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 U.S. Western and Eastern launch ranges.

Cryogenic Composite Tanks – XCOR Aerospace

XCOR Aerospace's new composite material (Nonburnite®)

The use of composite materials to manufacture large cryogenic fuel tanks is a critical enabler for RLVs and future lunar and Mars exploration missions. These tanks, which are currently made from aluminum, carry LOX, at -183 degrees Celsius (-298 degrees Fahrenheit). Aluminum shrinks approximately 0.5 percent when cooled to LOX temperatures. As a result, aluminum tanks cannot be rigidly attached to the vehicle structure, but must be suspended within it. Further, aluminum is flammable in LOX and strict precautions must be observed to prevent foreign objects from damaging the aluminum oxide layer that protects the aluminum tank from fire.

The payoff for using composite tanks is significant. Composite tanks are typically 10 to 25 percent lighter than comparably sized aluminum tanks, thereby, providing increased payload-to-orbit lifting capabilities for new ELVs and RLVs. Use of composite tanks also eliminates many engineering costs associated with mating aluminum cryogenic fuel tanks to composite launch vehicle structures.

In April 2006, XCOR Aerospace of Mojave, California, announced the successful testing of its new thermoplastic fluoropolymer composite material, Nonburnite®. Ignition and oxygen compatibility testing of XCOR's material was conducted at the NASA White Sands Test Facility in southwest New Mexico.

XCOR has been researching this technology since early 2004 and is currently developing it under a NASA contract for composite cryogenic LOX tanks. The contract, awarded in 2005, is part of the NASA Exploration Systems Research and Technology (ESR&T) program to develop key technologies for human exploration of the Moon, Mars and beyond. This new LOX tank technology shows dramatic weight savings by demonstrating the ability to serve as both an insulated tank and vehicle structure. Materials used in this tank retain flexibility and toughness at cryogenic temperatures and are inherently non-flammable, an important safety feature for LOX tanks on future human spaceflight vehicles.[38]

XCOR expects the performance of the new composite material will resolve existing problems with cryogenic and LOX materials. The material can be used by the aerospace industry in production of LOX tanks for fuel cells, life support systems, and small secondary propulsion systems, such as attitude control thrusters. Nonburnite's® thermal insulating properties, low coefficient of thermal expansion, and inherent combustion and microcracking resistance, as well as the high strength-to-weight ratio typical of composites, makes this material an enabling technology for building lighter, cheaper, more robust structures and crewed systems.

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

Composite Tanks – Microcosm, Inc.

Microcosm, Inc., of El Segundo, California, announced successful tests on two programs for composite tanks for launch vehicles in 2006. In June, Microcosm successfully tested a 64-centimeter (25-inch) diameter, all-composite LOX tank to nearly four times its operating pressure of 3,790 kilopascals (550 pounds per square inch). Testing occurred at cryogenic temperatures using liquid nitrogen. The new materials technology used for the tank comes from Composite Technology Development of Lafayette, Colorado. Testing was done for the Scorpius Space Launch Company. A month later, Microcosm announced the successful completion of final qualification tests on the full-scale, all-composite cryogenic LOX tank for the Sprite SLV. This time the testing was done for a full-scale, 107-centimeter (42-inch diameter), all-composite LOX tank to nearly four times its operating pressure of 3,790 kilopascals (550 pounds per square inch). This result allows for reduction in the weight of the propellant tanks for Sprite and increases the mass to orbit by over 30 percent. Microcosm intends to offer this technology in a range of sizes as well as custom-made pressure vessels for industrial applications where ultra-high strength-to-weight ratio is important.

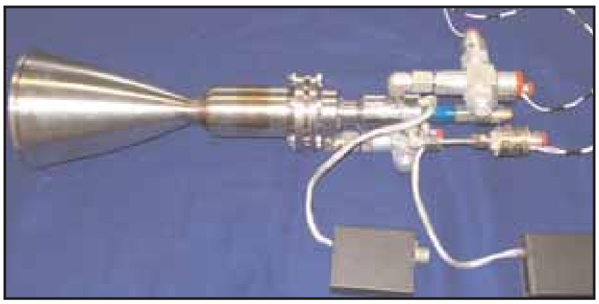
Microcosm Composite Tank

In June 2006, in a separate program, under contract to the AFRL, Microcosm tested a composite high-pressure gaseous helium tank to 100,000 kilopascals (14,500 pounds per square inch).[39] The 50-centimeter (20-inch) diameter, high-pressure helium tank is an Inconel-lined, composite over-wrap pressure vessel. This full-scale qualification tank for the High Performance Pressurization System for the Sprite SLV is also used in the SR-M suborbital launch vehicle being built for AFRL. The helium tank has been through 25 operating pressure cycles plus thermal cycling and is now fully flight qualified. Operating pressure for the helium tank is 38,600 kilopascals (5,600 pounds per square inch). The testing was done as part of the technology development program for the Scorpius family of low-cost, responsive launch vehicles.[40]

Automated Composite Technologies – Alliant Techsystems

In August 2006, ATK received a five-year contract from AFRL to develop automated composite technologies designed to reduce the manufacturing costs and increase the performance of large composite launch vehicle structures. Low cost tooling, filament winding techniques, integrated health monitoring, thermal protection systems, and tape lamination are among the 17 specific initiatives in the Large Automated Production of Expendable Launch Structures Program.

Liquid RCS Thruster – Orion Propulsion, Inc.



Oxygen/Methane RCS Thruster – in Sea Level Assembly

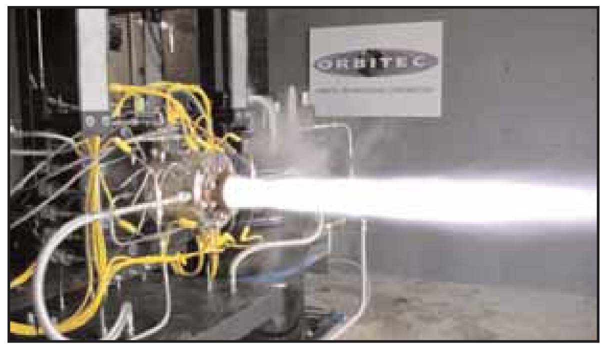
In October 2006, Orion Propulsion, Incorporated, of Huntsville, Alabama, was awarded new funds to continue developing the Oxygen-Methane (O/M) Reaction Control System (RCS) Thruster, under a NASA SBIR Phase 2 program. The new development stage will expand on the design of Orion's igniter/injector to provide simple and reliable ignition. Such system flexibility significantly increases the range of operating conditions for propellants that are stored at different saturated conditions. These efforts are a continuation from 2005, when Orion designed, manufactured, and tested a 445-newton (100-pound-force) O/M RCS thruster. During the first part of 2006, Orion developed another prototype test article, which is equipped with a flight type nozzle and propellant valves. Tests were performed in an environmental chamber at reduced pressure to simulate space vacuum conditions. The funding came through a NASA SBIR Phase 1 program.[41]

The O/M RCS Thruster has been tested in vacuum as well as sea level. After Phase 2 of the SBIR program is completed, this thruster will be able to operate on gaseous and liquid propellants, and it will have an integrated igniter/injector.[42]

The O/M RCS Thruster could be used in any NASA or commercial space launch vehicle or spacecraft that uses oxygen and methane for primary or maneuvering propulsion. The engine can also burn methane that is mined during Mars in-situ missions or stored on orbit for long-term missions.[43]

This engine offers many advantages over existing RCS thrusters, including flexibility, reusability, and high performance. The simple configuration and conventional manufacturing techniques contribute to cost, weight, and risk reductions.[44]

Liquid Engines – Orbital Technologies Corporation



ORBITEC's Vortex Engine Test

Continuing its efforts from 2005, Orbital Technologies Corporation (ORBITEC) of Madison, Wisconsin, developed new liquid engine technologies in 2006. Earlier in 2006, ORBITEC successfully demonstrated the ability to ignite a smallscale LOX/propane Vortex Combustion Cold-Wall (VCCW) engine. The company accomplished the engine firings under an AFRL Phase 3 SBIR contract.

For the demonstration, ORBITEC engineers successfully ignited the engine, refined the ignition sequence, and decreased the ignition duration, while avoiding a catastrophic explosion. One engine fired for a one-half-second duration with a 2,500-newton (560-pound-force) peak thrust; another fired for a 1-second duration with a 710-newton (160-pound-force) peak thrust. The chamber wall static pressure for these tests was 965 kilopascals (140 pounds per square inch absolute). Steady-state operation, which has yet to be demonstrated, will eventually occur at a chamber wall pressure of 1,380 kilopascals (200 pounds per square inch absolute) and a thrust of 3,560 newtons (800 pounds-force).

In a engine, hot combustion gases do not directly contact the combustion chamber wall. Therefore, the chamber wall is not exposed to high temperatures and remains cool, leading to increased engine durability. Vortex Combustion Cold-Wall technology is undergoing commercialization to enable affordable, high-performance, long-lasting suborbital launch vehicles.[45]

In November 2005, ORBITEC completed successful testing of a prototype rocket engine using methane fuel and oxygen oxidizer. Methane is of interest for NASA's exploration program and for future U.S. Air Force launch vehicles. This rocket requires smaller propellant tanks than hydrogen and has higher specific impulse than hydrocarbon fuels, such as kerosene. When used for exploration, methane and oxygen can be produced on the Moon and Mars from planetary resources found there.

At present, ORBITEC is perfecting patented designs for 133,500-newton (30,000-pound-force) thrust liquid methane-oxygen engines and liquid propane-oxygen vortex engines, with tests slated to begin in at least two years. The company's immediate planned tests focus on a 31,140 to 44,500-newton (7,000 to 10,000-pound-force) thrust vortex engine fueled by hydrocarbons and liquid oxygen. In July 2006, ORBITEC received a contract from the U.S. Air Force to continue its liquid engine development, as part of a broader solution for creating a cohesive universal small launch vehicle.[46]

Liquid Engines – AirLaunch LLC

AirLaunch Engine Firing

In 2006, AirLaunch continued development of LOX- and propane-powered, upper stage engines, as part of the Phase 2B DARPA/Air Force Falcon program contract. AirLaunch completed 32 horizontal engine test firings and increased the pace of propulsion testing. Twenty-eight of the tests were conducted between March and October 2006, including two per day for 3 days in a row. All the tests used the vapor pressurization (VAPAK) propulsion system, providing further data to validate its use with LOX and propane.[47]

In a previous stage of the contract, Phase 2A, AirLaunch conducted four second stage engine test fires as proof of concept for its VAPAK propulsion system using LOX and propane. The tests were conducted from April to June 2005 at the Civilian Flight Test Center, Mojave Spaceport. Testing demonstrated that the engine is stable, can be ignited quickly after shutdown, and is ready to move into the next phase of development.[48]

Liquid Engines – Space Exploration Technologies Corporation

SpaceX of El Segundo, California, completed development in early 2005 of two new liquid-propellant engines for use on its Falcon 1 launch vehicle. The first stage engine, known as Merlin 1A, is a high pressure 342,650-newton (77,000-pound-force) (sea level) thrust engine that is turbopump fed with a gas generator cycle. Merlin 1A has a chamber pressure of 5,380 kilopascals (780 pounds per square inch). The second stage engine, known as Kestrel, is a pressure-fed engine of 930 kilopascals (135 pounds per square inch) that produces 31,150-newton (7,000-pound-force) thrust (vacuum). Both engines use LOX and kerosene propellants.

SpaceX Merlin Engine

SpaceX began development of the Falcon 5 Merlin 1B upgrade engine in 2005. This engine has a thrust of 378,250 newtons (85,000 pounds-force) and a pressure of 6,140 kilopascals (890 pounds per square inch). The company initially planned to complete a Falcon 5 stage hold down firing with all Merlin 1B engines by the end of 2005, but plans changed. During 2006, SpaceX started working on the Merlin 1C engine, a regeneratively cooled successor of the Merlin 1B engine. SpaceX tested the pump and ignition systems, and the integrated engine was scheduled to begin testing by the end of 2006. The system is expected to be qualified by early 2007. A vacuum version of the

Merlin 1C, with a larger bell nozzle and some additional redundancy features, will be used on the Falcon 9's upper stage.

The next major engine development is Merlin 2, where SpaceX will aim for a significant increase in thrust and chamber pressure. A scaled-up version of Merlin 1, the Merlin 2 replaces the ablative chamber with a regeneratively cooled one.[49] The Merlin 2 will serve as an exact scale version of the F-1 class (>6,675,000-newton or 1.5 million-pound-force thrust) engine that SpaceX intends to start developing in a few years.[50]

Liquid Engines – XCOR Aerospace

XCOR Aerospace 5M15 LOX/methane engine test

XCOR Aerospace, located in Mojave, California, specializes in developing engines and propulsion systems for use on airplanes, reusable launch vehicles, and spacecraft. The company has developed and extensively tested seven liquid-propellant engines. XCOR's largest engine currently in active development, designated XR-5M15, is a 33,300-newton (7,500-pound-force) LOX and methane engine. In May 2006, XCOR signed a contract with ATK to develop and implement the prototype 5M15 engine for NASA. XCOR will develop the initial workhorse version of this engine, which ATK will then use as the basis for development of the final flight-weight hardware. The 5M15 builds upon XCOR's existing XR-3M9 LOX/methane engine, as well as the 8,007-newton (1,800-pound-force) XR-4K5, 44,482-newton (10,000-pound-force) XR-5M12, and 1,780-newton (400-pound-force) XR-4A3 engines.

XCOR Aerospace has a long history of developing different engine models using various non-toxic, or "green," propellants. Some of the prior designs it created include the XR4A3 LOX/alcohol engine that was flown on the EZ-Rocket, the XR-4K5, which is pump-fed and regeneratively cooled with fuel, and smaller engines, such as the nitrous oxide/alcohol XR-3B4, the LOX/alcohol XR-3A2, and the nitrous oxide/ethane XR-2P1.

The first series of tests on the XR-3M9 223-newton (50-pound-force) thrust rocket engine fueled by methane and liquid oxygen were completed in August 2005. Future generations of the 3M9 engine are intended for use as RCS and satellite maneuvering systems. The engine tests took place at XCOR's facilities at the Mojave Air and Space Port.[51]

In November 2005 XCOR successfully fired the XR-3M9 LOX/methane engine in short, rapid bursts. The testing consisted of four short pulses and the tests were done with self-pressurizing propellants. The rapid stop and restart pulse mode and minimum impulse bit that are required RCS applications were demonstrated during the test. This system has potential for a variety of space applications.

These tests, completed in January 2006, were conducted as part of a Phase 1 SBIR contract under AFRL's Propulsion Directorate at its Edwards Research Site and as part of development for an advanced regeneratively cooled LOX/methane engine for space applications.[52]

In October 2006, XCOR Aerospace announced the completion of another successful round of tests on its 6,670-newton (1,500-pound-force) thrust LOX/kerosene rocket engine. The engine, the XR-4K14, is a prototype of the engines that will soon propel the Mark One Rocket Racer, into the new sport of rocket racing. This set of tests has demonstrated that the XR-4K14 rocket engine chamber design is sound. Multiple runs of increasing duration were performed in order to allow for the characterization of the engine's regenerative cooling. XCOR's engines have a total of over 2,750 firings and 320 minutes of run time. All of its engine tests take place at XCOR's facilities at the Mojave Air and Space Port.[53]

Liquid Engines – Microcosm, Inc.

Ablative Composite Rocket Engine

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 is planned be used as the upper stage engine for the Sprite Mini-Lift orbital vehicle should that vehicle move into final development.

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 1- to 30-second tests, involving multiple injectors, chambers, and operating pressures. Testing was the combined effort of Microcosm; Sierra Engineering of Carson City, Nevada, which designed the injector for the engine; and AFRL at EAFB 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 U.S. Air Force Falcon Small Launch Vehicle program.[54] During 2006, Microcosm continued to develop their new larger 89,000-newton (20,000-pound-force) ablative engine.[55]

In September 2006, Air Force eliminated funding for the Scorpius program. Consequently, future Microcosm engine development plans depend on available funding.

In addition, Microcosm has started development on a new 356,000-newton (80,000-pound-force) engine under an AFRL SBIR, Phase 1 contract. Both the 89,000-newton (20,000-pound-force) and 356,000-newton (80,000-pound-force) engines are follow-on developments to the successful 22,250-newton (5,000-pound-force) engines. All are ablative chamber, LOX and Jet A propellant engines, designed for very low-cost, robust design margins, moderate chamber pressures, high reliability, and expendable applications.

Liquid Engines – Pratt & Whitney Rocketdyne

Pratt & Whitney Rocketdyne, Inc.—a Business unit of Pratt & Whitney—is developing new technologies and engines for space launch vehicles. 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 IPD engine with the U.S. Air Force and NASA and on the new MB-XX upper stage cryogenic engine—to verify their characteristics.

MB-XX Engine

The MB-XX is being developed on funding from Pratt & Whitney Rocketdyne and Mitsubishi Heavy Industries for potential application to the Vision for Space Exploration launch vehicles or upgrades to today's EELVs. Rocketdyne completed preliminary design review (PDR) on the RS-84 rocket engine, which is the first reusable, hydrocarbon-staged, combustion rocket engine.

The first member of the MB-XX family to begin development, the MB-60 engine was originally targeted for use on the Delta 4 launch vehicle.[56] 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. Propellants for this engine are liquid oxygen and liquid hydrogen. The engines can be calibrated to operate at a normal mixture ratio in excess of

6.0 (oxygen over fuel). Calibration of the basic engine is accomplished using orifices to control thrust and mixture ratio, but the design can be modified should throttling be required. Selection of the expander-bleed cycle enables operation at high-chamber pressure (10,340 to 13,780 kilopascals or 1,500 to 2,000 pounds per square inch absolute) and hence high performance within a compact package at a cost comparable to existing engines. The expander-bleed cycle used in the MB-XX engine differs from the closed, full expander cycle used in RL10, RL60, and Vinci engines.[57]

Aerospike Liquid Engine – Garvey Spacecraft Corporation

GSC/CSULB Aerospike Engine

Garvey Spacecraft Corporation and CSULB conducted several notable small launch vehicle R&D activities through their partnership in the California Launch Vehicle Education Initiative during 2005. Using a single-chamber, liquid propellant, annular aerospike engine concept 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 and 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 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.

Another important milestone was achieved by the joint industry-academic team in December 2004 when it conducted its initial launch and recovery of a full-scale flight development unit for NLV. The Prospector 5 vehicle, an early version of the NLV first stage, was launched and then recovered by parachute.[58]

In October 2005, the GSC/CSULB CALVEIN team conducted two static fire tests. The first of these tests involved a 5,340-newton (1,200-pound-force) thrust engine that featured a new epoxy resin for the ablative chamber liner. This basic engine design is the same one that has powered the Prospector 4, 5, 6 and 7 vehicles. The second static fire test focused on the initial operation of a 225-newton (50-pound-force) engine module that CSULB is developing for future multichamber aerospike engine configurations. The tests took place at the Friends of Amateur Rocketry, Incorporated, test site in the Mojave Desert.[59] Currently, GSC and CSULB continue their cooperation for developing a next-generation, multiple-chamber aerospike engine, under a research grant from Missile Defense Agency. A flight test of this engine on GSC's Prospector 10 rocket is planned for mid-2007.

Integrated Powerhead Demonstration – NASA

The Integrated Powerhead Demonstration is a joint venture between NASA and the Integrated High Payoff Rocket Propulsion Technologies program managed for DoD by the AFRL at EAFB and NASA Marshall Space Flight Center. This project is a single phase program designed to demonstrate the technologies needed for a possible future full-flow, staged-combustion flight engine. The engine has been designed as a reusable engine system, capable of up to 200 flights, and features high-performance, long-life technologies and materials. The IPD will employ dual preburners that provide oxygen- and hydrogen-rich staged combustion.

IPD test at Stennis Space Center

Pratt & Whitney Rocketdyne is developing the liquid hydrogen fuel turbopump, oxygen pump, main injector, and main combustion chamber of the demonstrator. Aerojet Corporation of Sacramento, California, designed and tested the oxidizer pre-burner, which initiates the combustion process with oxygen-rich steam. Aerojet also is responsible for development of the demonstrator engine's fuel pre-burner, designed to supply fuel to the turbopump's turbine with hot, hydrogen-rich steam. Pratt & Whitney Rocketdyne will lead overall system integration once component-level development and testing are complete. The IPD underwent system level testing at the Stennis Space Center between February 2005 and August 2006, completing 23 tests and accumulating 429 seconds of operation at power levels up to 100 percent.[60]

This full-flow, staged-combustion cycle uses a fuel-rich preburner to drive the fuel turbopump and an oxidizer-rich preburner to drive the oxygen turbopump. Because all of the propellants are burned in the preburners, more mass flow is available to drive the turbines than in a conventional staged combustion cycle. The additional power enables lower turbine temperatures and hence less stress, translating into longer turbine life, a key factor for reusable rocket engine life. In addition, the use of oxidizer-rich gas in the oxidizer turbine and fuel-rich gas in the fuel turbine eliminates the need for a complex propellant seal for the pumps. Elimination of inadvertent propellant mixing failure modes at the seals increases engine system reliability. The innovation also includes a hydrostatic bearing technology that literally floats the turbine shaft on rocket propellants, eliminating wear and enabling high reusability.[61]

Hybrid Rocket Motors – SpaceDev, Inc.

In 1998, SpaceDev, Incorporated, 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.

In November 2005, SpaceDev announced the award of a $2.7 million contract by the Air Force to begin work on a large hybrid rocket motor. SpaceDev is to design, develop, and test a small common booster capable of producing about 445,000 newtons (100,000 pounds-force) of thrust, almost nine times that of the SpaceDev rocket motor technology used in SpaceShipOne.

In 2006, SpaceDev constructed a hybrid motor test stand at the Northrop Grumman Capistrano Test site in San Clemente, California. The current thrust stand configuration has a 22,241-newton (5,000-pound-force) thrust capacity with plans to expand the site to 1.1 million-newton (250,000-pound-force) thrust. SpaceDev fired two hybrid upper stage motors at the site in 2006, which provided data on motor performance and stability. More firings are planned in 2007.[62]

SpaceDev anticipates that the technology will validate the ground test configuration of critical elements of the hybrid motor, such as the injectors, igniters, the motor grain, and insulation. The overall goal is to demonstrate successful ignition and operation of a booster stage hybrid motor that can produce a reliable and reproducible thrust profile, with high performance.[63]

SpaceDev Hybrid Upper Stage Ground Fire Test

Hybrid Propulsion Systems – Lockheed Martin-Michoud

Hybrid motors combine the best of solid and liquid propulsion systems, typically using an inert fuel and liquid oxygen to generate thrust. Hybrid propulsion offers significant gains in safety, throttle-ability, cost, and effect on the environment. Lockheed Martin has developed hybrid propulsion systems since 1989 and performed over 600 motor firings, including a successful launching of a 267,000-newton (60,000-pound-force) thrust sounding rocket from NASA Wallops Island, Virginia, in 2003.[64]

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.[65]

In June 2005 Lockheed Martin successfully test-fired a hybrid motor as part of the FALCON SLV program at the AFRL, EAFB. This test was the second SLV hybrid motor firing that Lockheed Martin conducted at Test Stand 2-A in 2005; the first one took place in January.[66] The hybrid motor that was tested was a full-scale test version of the upper stage motor on Lockheed Martin's SLV and measured almost 3.5 meters (11 feet) in length and 1.5 meters (5 feet) in diameter. The motor fired for its planned duration of 120 seconds, which was twice the length of time of the first firing. Lockheed Martin believed that the 120-second test was the longest burn of a hybrid motor at that scale. The fuel grain was designed such that the 120-second firing represented over 170 seconds of run time for the flight configuration.

Hyper-X Series Vehicles – NASA

X-43A/Hyper X

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.

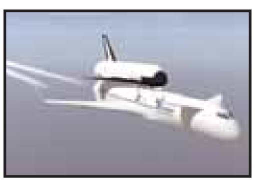
On March 27, 2004, four decades of supersonic combustion ramjet (scramjet) propulsion research culminated in a successful flight of the X-43A hypersonic technology demonstrator, the first time a scramjet-powered aircraft had flown freely. On November 16, 2004, an identical scramjet-powered X-43A repeated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

In October 2005, ATK received a five-year, $15 million contract from NASA, 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.

In December 2005, ATK, DARPA, and Office of Naval Research (ONR) successfully ground-launched and flew a hypersonic scramjet-powered vehicle from the Wallops Flight Facility, Wallops Island, Virginia. This launch was the first free flight of a scramjet-powered vehicle, using conventional liquid hydrocarbon jet fuel. The launch and flight test were part of the Freeflight Atmospheric Scramjet Test Technique (FASTT) program sponsored by DARPA and ONR. The approximately 2.7-meter (9-foot) long, 28-centimeter (11-inch) in diameter FASTT vehicle integrated a scramjet engine into a missile configuration. After separating from its booster rocket at more than 18.3 kilometers (60,000 feet), the scramjet engine ignited and propelled the vehicle at approximately 1,615 meters per second (5,300 feet per second) or Mach 5.5. Using JP-10 fuel, the scramjet flew for at least 15 seconds while critical engineering data was captured via on-board sensors and tracking radars.[67]

In September 2006, through a series of tests, ATK demonstrated that its hypersonic engine technology has practical, near-term applications for a range of potential missions, including weapons and platforms. These tests were conducted at NASA Langley Research Center using an ATK-designed, thermally throated, ramjet combustor rig. During the series of tests, ATK's hypersonic combustor completed more than 72 minutes of combustion time with liquid fuel. The ultimate objective is to develop a flight engine designed specifically for wide operability margin and simplicity. Recent hypersonic tests were conducted in three series, ranging from Mach 3.7 to 5.3. The flight-weight, fuel-cooled combustor was tested for 23 minutes of hot (combustion) time. Individual tests lasted up to 2.5 minutes to achieve thermal equilibrium. The duration of the tests also helped ATK gain data in the extreme temperature environment of hypersonic flight. The fuel-cooled combustor was successfully tested in both open and closed loop configurations where the fuel used for cooling was directly injected into the combustion chamber. In addition, ATK successfully demonstrated an efficient combustor start on cold fuel with subsequent transition to fuel vapor as the rig heated up. The combustor exhibited extremely wide throttle-ability at all conditions, confirming the robustness of the design and clearing the path to freejet tests of a complete fuel-cooled engine that are now underway.

Propellant Production – Andrews Space, Inc.



Gryphon with Orbiter

Andrews Space, Incorporated, of Seattle, Washington, has developed an in-flight propellant collection system, the "Alchemist" Air Collection and Enrichment System (ACES), which generates LOX through the separation of atmospheric air. The 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 take-off weight, increasing payload capability, or both. By allowing vehicles to take off without LOX onboard, ACES technology allows a dramatically smaller launch vehicle for a given payload size. Because LOX represents a significant fraction of take-off weight, this approach 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.

The company has proposed Alchemist™ ACES in conjunction with its two-stage-to-orbit RLV design—known as Gryphon—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 Space Launch Initiative (SLI) contract. ACES was first demonstrated in the 1960s for the U.S. Air Force Aerospaceplane program.[68]

In 2005, DARPA awarded Andrews a contract to conduct system testing. Under this initial contract, valued at $653,000, Andrews demonstrated basic system technologies. In addition, Andrews designed and built a rotating test apparatus to conduct advanced cryogenic testing.

In March 2006, DARPA/AFRL awarded Andrews Space, Incorporated, additional funding to demonstrate operational capabilities of its Alchemist™ ACES. Under the new contract, valued close to $350,000, Andrews will advance the state-of-the-art and demonstrate critical ACES components and operating parameters. This bridge funding is meant to permit early demonstration of the technologies required and to reduce program risk for the demonstration program significantly. Development and demonstration of these technologies offers a new hybrid approach to rocket propulsion, which can significantly reduce takeoff gross weight.[69]

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 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 federal facilities, commercial payload customers have become frequent users. 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, the FAA has licensed the operations of six non-federal launch, reentry, or both, sites. These spaceports serve both commercial and government payload owners.

Table 2 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 2: Spaceport Summary by State

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

Non-federal Spaceports

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 the FAA. To date, six non-federal launch sites (see Table 3). Three are co-located with federal launch sites, including the California Spaceport at VAFB, Cape Canaveral Spaceport operated by Space Florida at CCAFS, and the Mid-Atlantic Regional Spaceport at Wallops Flight Facility, Virginia. In addition, Blue Origin utilizes an exclusive use launch site in western Texas that is not an FAA licensed spaceport. Similarly, Sea Launch also does not need an FAA launch site operator license. The first orbital launch from an FAA-licensed site occurred on January 6, 1998, when a Lockheed Martin Athena 2, carrying NASA's Lunar Prospector spacecraft, successfully lifted off from the spaceport operated by Space Florida's LC-46. Table 3 summarizes the characteristics of FAA licensed spaceports.

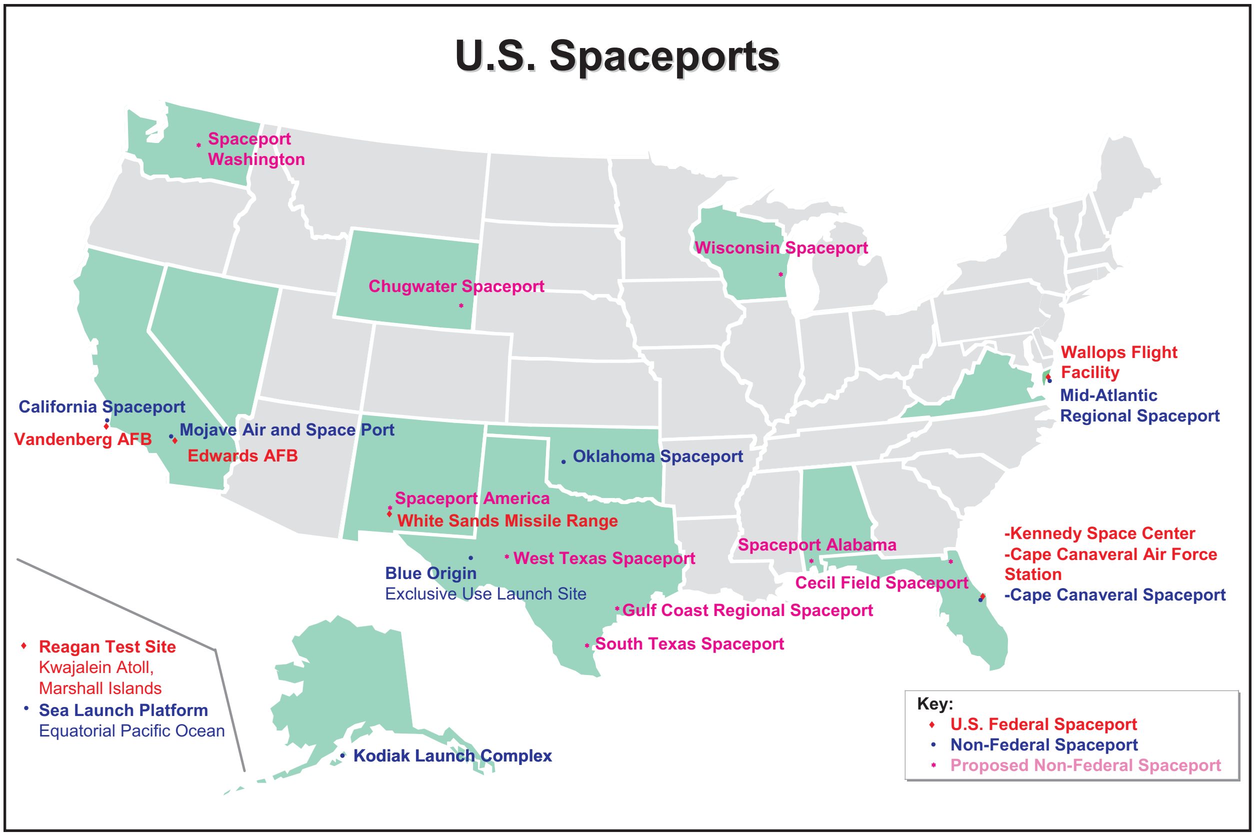
Blue Origin West Texas Launch Site

Blue Origin West Texas launch site is a private property owned by Jeff Bezos, the founder of Amazon.com and Blue Origin, LLC. After purchasing almost 66,800 hectares (165,000 acres) of desert 40.2 kilometers (25 miles) north of Van Horn, in Culberson County, Texas, the entrepreneur expressed interest in building and operating a private spaceport. Blue Origin proposes to launch RLVs on suborbital, ballistic trajectories to altitudes in excess of 99,060 meters (325,000 feet). To conduct these operations, Blue Origin would construct a private launch site, including a vehicle processing facility, launch complex, vehicle landing and recovery area, spaceflight participant training facility, and other support facilities.[70]

After reviewing the environmental assessment and finding of no significant impact for the proposed Blue Origin West Texas launch site, FAA issued to Blue Origin the first experimental permit for a reusable suborbital rocket in September 2006. This type of permit was first authorized by the

Table 3: Non-federal Spaceports Infrastructure and Status

Spaceport	Location	Owner/Operator	Launch Infrastructure	Development Status
Blue Origin West Texas Launch Site	Culberson County, Texas	Blue Origin	No known infrastructure at this time.	Blue Origin plans to construct a private launch site, including a vehicle processing facility, launch complex; vehicle landing and recovery areas; and space flight participant training facility. Blue Origin received the first experimental permit for a reusable suborbital rocket in September 2006 and executed a test launch in November 2006.
California Spaceport	Vandenberg AFB, California	Spaceport Systems International	Existing launch pads, runways, payload processing facilities, telemetry, and tracking equipment.	Site is operational.
Cape Canaveral Spaceport	Cape Canaveral, Florida	Space Florida	One orbital launch complex with a remote control center, one suborbital launch complex with two pads and a blockhouse, an off-site solid rocket motor storage that includes heavy rail access, a 27-m (90-ft) high bay with overhead cranes, a storage building, and an RLV support facility.	Construction of a quadra-axial static rocket motor test stand planned for spring of 2007.
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, and maintenance and storage facilities.	In 2006, AADC added eight additional redundant telemetry links to its range safety and telemetry system. Paving of improved road scheduled for completion in 2007.
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, mobile liquid fueling capability, on-site and downrange telemetry and tracking, and payload recovery capability.	Infrastructure improvements planned for 2007 include an enhanced capability for Pad 0-B gantry and additional improvements to the high bay within the logistics and processing facility.
Mojave Air and Space Port	Mojave, California	East Kern Airport District	Air traffic control tower, three runways, rotor test stand, engineering facilities, high bay building. Easy access to restricted airspace. Space zoned specifically for rocket motor development and testing.	Runway 12-30 extension to 3,810 m (12,500 ft) completed in November 2006. Construction beginning in 2007 of an extension of runway 8-26, a new fire suppression water storage tank and water main, and an emergency response facility and equipment for protection of the involved public during planned suborbital spaceflight.
Oklahoma Spaceport	Washita County, Oklahoma	Oklahoma Space Industry Development Authority	A 4,115-m (13,500-ft) runway; 5,200-m^2 (50,000-ft^2) manufacturing facility; 2,7850-m^2 (30,000-ft^2) maintenance and painting hangar; 6 commercial aircraft hangars, including a 2,787-m^2 (30,000-ft^2) maintenance and paint facility; 39-ha (96-a) of concrete ramp, control tower, crash and rescue facility; and 435-km^2 (168-m^2) of land available for further construction.	The Clinton-Sherman AFB at Burns Flat was designated as the future spaceport. OSIDA received a Launch Site Operators License from the FAA in June 2006.



Commercial Space Launch Amendments Act of 2004. The vehicle to be tested will be uncrewed and will be launched and landed vertically during tests. The permit granted to Blue Origin is a 1-year, renewable permit, allowing for unlimited launches. Such permits are intended to allow launch vehicle developers to flight test their designs.[71] On November 13, 2006, Blue Origin executed the first test launch from its West Texas facility, performing a low-level flight test of a prototype of its New Shepard RLV.[72]

California Spaceport

On September 19, 1996, the California Spaceport became the first Commercial Spaceport licensed by FAA. 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 34 degrees North latitude, 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.

Construction of the California Spaceport, 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 were routed underground to provide a launch pad with the flexibility to accommodate a variety of launch systems. The current Space Launch Complex (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. Recently, plans have been developed to expand the height of the tower on SLC-8 to support the Minotaur 4 launch system.[73] 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

California Spaceport

Room. Located near SLC-6, this large clean room facility was designed to process three Space Shuttle payloads simultaneously. Now, the facility is leased and operated by the California Spaceport as the IPF; payload-processing activities occur on a regular basis. The IPF has supported booster processing; upper stage processing; encapsulation; and commercial, civil, and military satellite processing and their associated administrative activities. The IPF can handle all customer payload processing needs. This capability includes Delta 2, Delta 4, and Atlas 5 class payloads as well as smaller U.S. Air Force and commercial payloads.

In 2002, SSI won a 10-year U.S. Air Force 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 contract covers 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 at VAFB. In 2005, SSI supported two payload-processing flows through the IPF and two successful Minotaur launches from SLC-8. In April 2006, SSI supported the integration and launch of a Minotaur, carrying the COSMIC mission from SLC-8.[74]

Cape Canaveral Spaceport

Space Florida, created on May 30, 2006, consolidates Florida's space and aerospace entities and coordinates all space-related issues in Florida. Space Florida promotes and facilitates launch activity within the state by supporting and assisting commercial launch operators in completing required documentation and gaining approvals from the required federal agencies for launching from Florida. Space Florida can lend money for its purposes, own, acquire, construct, and reconstruct facilities related to launch. It has the authority to issue revenue bonds and any other bonds to facilitate development and is authorized to own a variety of infrastructure support systems including electric power plants and transportation facilities. Under an arrangement between the federal government and Space Florida, excess CCAFS facilities were licensed to Space Florida for use by commercial launch service providers on a dual-use, non-interference basis.

Panther-1

Major infrastructure operated by Space Florida at CCAFS includes Launch Complex-46 (LC-46), a refurbished 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).

As part of an overall effort to expand use of the Cape for research, development, and educational activities, Space Florida obtained a 5-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. Plans are underway to begin construction in the spring of 2007 of a quadra-axial static rocket motor test stand capable of accommodating motors up to 30 centimeters (12 inches) in diameter with a maximum average thrust of 53,400 newtons (12,000 pound-force).

Space Florida's new Board of Directors is developing a Strategic Plan that includes potential commercial spaceport development projects at both the existing spaceport and other sites around the state. Space Florida is helping Florida airports apply for an FAA Launch Site Operators license to support horizontally-launched spacecraft. In July

2006, the Jacksonville Aviation Authority began the site license process for Cecil Field.[75] Space Florida is also working with NASA KSC to identify ways to partner on the commercialization of the Shuttle Landing Facility and development of an aerospace technology and commerce park.

A Super Loki rocket, carrying Project Genesis, was launched from Space Florida facilities on May 12, 2006. The Panther-1 rocket launched on June 28, 2006, representing the first ever student-designed and -built vehicle to launch from the Spaceport Operated by Space Florida.[76]

Kodiak Launch Complex

KLC FTG-02 Launch

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, 2-year construction of the Kodiak Launch Complex (KLC) at Narrow Cape on Kodiak Island, Alaska. The first licensed launch site not co-located with a federal facility, 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 KLC received initial funding from the U.S. Air Force, U.S. Army, NASA, 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 on which the spaceport resides.

Kodiak has conducted ten successful launches since 1998. Located at 57 degrees North latitude, 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 5-kilometer (3-mile) area around 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 990 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 include the Launch Control Center; Payload Processing Facility, which includes a Class-100,000 clean room, an airlock, and a processing bay; Launch Service Structure and orbital Launch Pad 1; Spacecraft and Assemblies Transfer Facility and suborbital Launch Pad 2; Integration and Processing Facility; and 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. Future expansion plans include building a second suborbital launch pad and a motor storage facility, and increasing fiber-optic bandwidth to the continental United States. Paving of improved roadways to the KLC is scheduled for completion in 2007.

The KLC Range Safety and Telemetry System (RSTS) was delivered in September 2003 and upgraded in 2005. This 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. In 2006, eight additional redundant links were added to the system for a total of twelve redundant links available at the KLC and the off-axis site in Cordova.[77]

The MDA conducted target missile launches from KLC in February 2006 and September 2006.[78] A five-year contract was signed in 2003 between MDA and AADC to provide launch support services for multiple launches in connection with tests of the nation's missile defense system.

Mid-Atlantic Regional Spaceport

Mid-Atlantic Regional Spaceport

MARS is designed to provide "one-stop shopping" for space launch facilities and services for commercial, government, scientific, and academic users. From its location on the Atlantic coast, this spaceport can accommodate a wide range of orbital inclinations and launch azimuths. Optimal orbital inclinations accessible from the site are between 38 degrees and 60 degrees; other inclinations, including Sun-synchronous orbit (SSO), can be reached through in-flight maneuvers.

The FAA issued a launch site operator's license to the Virginia Commercial Space Flight Authority (VCSFA) in December 1997. In July 2003, a bi-state agreement was created between Virginia and Maryland to jointly operate, conduct future development, and promote the spaceport. The agreement also renamed the spaceport to MARS.

MARS will receive over $350,000 directly from Virginia and Maryland in fiscal year 2007. In addition, these states will provide tax exemptions, tax credits, work force training funds, and infrastructure grants to support spaceport development.

DynSpace, a subsidiary of Computer Sciences Corporation, is the primary support contractor for MARS. In 1997, VCSFA signed a Reimbursement Space Act Agreement with NASA to use the WFF infrastructure to support commercial launches. This 30-year agreement allows MARS 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.

MARS has two launch pads. Launch pad 0-B, 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. The 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. In March 2000, MARS acquired a second pad at WFF, launch pad 0A. 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 can place up to 1,350 kilograms (3,000 pounds) into LEO.

MARS is in the process of constructing a $4 million logistics and processing facility at WFF that includes high bay and clean room environments. In 2006, MARS began Phase 2 construction of a Class-100,000 high bay within the facility.[79] In conjunction with WFF, MARS has also constructed a mobile Liquid Fueling Facility capable of supporting a wide range of liquid-fueled and hybrid rockets. Future infrastructure improvements plans include enhanced capability for Pad 0-B gantry and additional improvements to the high bay.

Highlights for 2006 include the successful Minotaur launch in December of TacSat-2. In September, the successful completion of the NASA ALV-X1 Pathfinder operation resulted in a contract from NASA for the launch of the ALV-X1. Upcoming launches for MARS include the U.S. Air Force and NASA NFIRE launch in April 2007 and the TacSat-3 launch in November 2007.[80] The spaceport has an interest in supporting future RLVs, possibly using its launch pads or three runways at WFF.[81]

Mojave Air and Space Port

Mojave Air and Space Port

Mojave Airport in Mojave, California, became the first inland launch site licensed by the FAA on June 17, 2004, allowing the 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.

Now known as the Mojave Air and Space Port, infrastructure includes an air traffic control tower with Class D airspace and three runways with associated taxiways. Runway 12-30 is the primary runway for large air carrier jet, high-performance civilian and military jet aircraft and horizontal launch spacecraft. An extension of runway 12-30 from 2,896 meters (9,502 feet) long to 3,810 meters (12,500 feet) was declared ready for use on December 5, 2006. 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. The extension of runway 12-30 and over $250,000 of repairs to the airfield and taxiways were completed in November 2006. The cost of infrastructure upgrades totals $10.5 million with 95 percent of the funding provided by the FAA and 5 percent by the East Kern Airport District.[82]

Mojave Air and Space Port serves as a Civilian Flight Test Center with access to R-2508 restricted airspace. The airport has 162 hectares (400 acres) of land available for immediate construction. In addition, over 121 hectares (300 acres) are zoned specifically for rocket motor testing and development. Currently six companies are actively developing and testing rocket motors.

Infrastructure upgrades planned for 2007 include an extension of runway 8-26 from 2,149 meters (7,050 feet) long to 3,505 meters (11,500 feet). Construction will begin on a 3.8-liter (one-million-gallon) fire suppression water storage tank and new 56-centimeter (22-inch) water main for taxiway B. In addition, an emergency response facility and associated equipment for protection of involved public during suborbital research and development and passenger spaceflight are planned.

Major facilities at the Mojave Air and Space Port include the terminal and industrial area, hangars, offices, maintenance shop, fuel services facilities, aircraft storage, and reconditioning facilities. Numerous large air carrier jet aircraft are stored and maintained at the Mojave Air and Space Port. The airport is home to a variety of organizations, including BAE Systems, Fiberset, General Electric, Interorbital Systems, Masten Space Systems, the National Test Pilot School, Scaled Composites, Orbital Sciences, and XCOR Aerospace.

Mojave Air and Space Port has hosted several record-breaking events in the last few years. The June 21, 2004, flight of SpaceShipOne made Mike Melvill the first civilian astronaut. SpaceShipOne rocketed past the boundary of space on September 29, 2004, and again on October 4, 2004, to win the $10 million Ansari X Prize. In December 2005, the EZ-Rocket made a record-setting point-to-point flight, departing from the Mojave Air and Space Port, and gliding to a touchdown at a neighboring airport in California City.[83] In February 2006, XCOR Aerospace conducted flight testing of its Mark 1 Rocket Racing aircraft at the Mojave Air and Space Port. In April 2006, Scaled Composite's White Knight took off from Mojave Air and Space Port to conduct flight tests of the DARPA-sponsored X-37.

Oklahoma Spaceport

Oklahoma Spaceport

After seven years of development, in June 2006, the Oklahoma Spaceport became the sixth commercial spaceport licensed by the FAA. 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 100 percent of the operational funding for OSIDA, but the organization expects to be financially independent in the future, particularly now that it holds a commercial launch site operator license. Still, direct financial support varies with specific needs for facility upgrades or operations. OSIDA intends to submit a request for one-time capital expenditures for facility upgrades and expects to receive the support during fiscal year 2008. The environmental assessment that was initiated in 2002 concluded in May 2006, when the FAA found that issuing a launch site operator license to OSIDA would not significantly affect the quality of the environment, as defined by the National Environmental Policy Act.[84] Besides state funding, NASA issued a $915,000 grant to OSIDA for aerospace education programs.

The FAA license allows OSIDA to provide launch and support services for horizontally launched suborbital RLVs at the Clinton-Sherman Industrial Airpark (CSIA) launch site, located near Burns Flat. On December 5, 2006, the city of Clinton conveyed ownership of the CSIA to OSIDA. 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. Existing buildings could serve to house space planes, manufacturing facilities, and even a passenger terminal.[85] Infrastructure development plans for fiscal year 2008 include additional fencing for the spaceport and development of a Fight Operations Control Center, located in the OSIDA headquarters.

Oklahoma's site license clears the spaceport for suborbital flights in a 110 x 270 kilometer (70 x 170 mile) corridor of the prairie, with clearance for launch vehicles to rise to the fringe of outer space.[86] In June 2006, OSIDA signed a letter of agreement with Fort Worth Air Route Traffic Control Center that provides procedures for the integration of licensed launch operations into the National Airspace System from the Oklahoma Spaceport.[87] Thus, this launch site became the first U.S. inland spaceport licensed to fly in the national airspace system, clear of military operating areas or restricted government flight corridors. This arrangement means that spacecraft will not need military permission to operate because the spaceport will have its own air space. The license was granted for five years and the FAA will schedule safety inspections of the spaceport at least once a year. Before a vehicle launch, individual operators will need to apply for a separate launch license or permit from the FAA.

Oklahoma Department of Commerce offers several incentives to attract space-related businesses. For example, a jobs program provides quarterly cash payments of up to 5 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 Kistler and TGV Rockets, Incorporated, have located in Oklahoma for their launch vehicle developments. As the first corporation that meets specific qualifying criteria, including equity capitalization of $10 million and creation of at least 100 Oklahoma jobs, Rocketplane Kistler has qualified so far for a $18-million, state-provided tax credit. Another company pursuing space-related activities in Oklahoma, Armadillo Aerospace, conducted tethered operational testing at the Oklahoma Spaceport with the vehicle that was used for the 2006 X Prize Lunar Lander competition.[88]

Table 4: 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.	Site is operational.
Edwards AFB	California, near Mojave	U.S. Air Force	Telemetry and tracking facilities, jet and Shuttle capable runways, reentry corridors, operations control center, movable hangar, fuel tanks, and water tower.	Site is operational.
Kennedy Space Center	Cape Canaveral, Florida	NASA	Launch pads, supporting Space Shuttle operations, the Vehicle Assembly Building (VAB), and the Shuttle Landing Facility.	Environmental assessment underway for the utilization of the Shuttle Landing Facility for commercial suborbital and orbital spaceflight, special purpose aviation, and other compatible uses.
Reagan Test Site	Kwajalein Island, Republic of the Marshall Islands	U.S. Army	Telemetry and tracking facilities, range safety systems, runway, and control center.	Site is operational. New launch pad on Omelek Island completed in 2006.
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, and Shuttle-capable runways.	Site is operational.

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. CCAFS and VAFB host pads for the Delta 2, Delta 4 and Atlas 5.

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 U.S. Air Force, 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 U.S. Air Force, and considering them in the existing U.S. Air Force requirements process. Table 4 summarizes the characteristics of federal spaceports.

Cape Canaveral Air Force Station

The 45th Space Wing, headquartered at Patrick AFB, conducts launch operations and provides range support for military, civil, and commercial launches at 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 45th Space Wing manages the Eastern Launch and Test Range (ELTR). The ELTR collects, processes and delivers data for a variety of ELTR

Cape Canaveral Air Force Station

range users, as well as protecting the public from the hazards of launch activities. To accomplish these tasks, the range consists of a series of tracking, telemetry and commanding 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 airborne or seaborne assets, as well as a site located in Argentia, Newfoundland.[89] Users of the ELTRS include the U.S. Air Force, U.S. Navy, NASA, and various private industry contractors.

Launch agencies at CCAFS process a variety of satellites and launch them on Atlas 5, Delta 2, and Delta 4 ELVs. The spaceport also provides support for the Space Shuttle program, which launches from KSC, and U.S. Navy submarine ballistic missile testing.

The ELTR supported many successful launches in 2006, including an Atlas 5 launch of the Pluto New Horizons mission, Atlas 5 launch of ASTRA 1KR, Delta 4 launch of GOES-N, Delta 2 launch of Mitex, Delta 2 launches of GPS IIR-15 and -16, and the Delta 2 launch of STEREO.

Edwards Air Force Base

Edwards Air Force Base

The original landing site for the Space Shuttle, Edwards Air Force Base (EAFB) California, is the home of more than 250 first flights and about 290 world records. The first two Shuttle flights landed on Rogers Dry Lake, a natural, hard-pack lake bed, measuring about 114 square kilometers (44 square miles). Today, NASA prefers to use KSC as the primary landing site for the Space Shuttle and uses EAFB as a back-up site. EAFB is operational for horizontal takeoff and landings, but is not operational as a launch site. Edwards is the DoD's premier flight test center, leading in unmanned aerial vehicle (UAV), electronic warfare, directed energy test capabilities, and testing of future hypersonic vehicles.

Within the last 10 years, EAFB has been the home of more than 10 experimental projects, among them the X-33 aerospace plane. Although the X-33 was never tested and its launch site is not operational, considerable capability exists at Edwards's Ridley Mission Control Center for support of aircraft and spacecraft during re-entry and landing. In 2006, three glide tests were successfully completed on the DARPA-sponsored X-37 autonomous research vehicle.

Edwards completed an environmental assessment for reentry corridors to EAFB for lifting entry vehicles like the X-38 configuration.[90] An additional environmental assessment is being developed for corridors that will allow hypersonic flight tests within the atmosphere for ranges of 741 kilometers (400 nautical miles) and 1,528 kilometers (825 nautical miles).

Kennedy Space Center

ZERO-G at Kennedy Space Center

Established as NASA's Launch Operations Center in July 1962, KSC today serves as the primary launch site for NASA's crewed space missions. Major KSC facilities comprise Launch Complex 39, supporting Space Shuttle operations; the Vehicle Assembly Building (VAB), where the Shuttle is integrated; and the Shuttle Landing Facility. A diversity of payload processing and support facilities are available for multiple users. Kennedy Space Center provides oversight of NASA's ELVs that are flown primarily from CCAFS and VAFB with support from the U.S. Air Force.

During 2006, KSC supported the successful launch of the New Horizons, Space Technology 5 (ST5), CALIPSO, CloudSat, and the twin Solar Terrestrial Relations Observatories (STEREO) spacecraft. KSC also supported NASA's Shuttle Discovery (STS-116 and STS-121) and Shuttle Atlantis (STS-115) missions to the ISS. NASA and HDNet signed an agreement in March 2006 to allow HDNet to broadcast in high definition shuttle liftoffs and landings at KSC through 2010.[91]

In September 2006, KSC issued a Request for Proposals (RFP) for the selection of a master developer for a 129-hectare (319-acre) aerospace technology and commerce park at KSC. The Exploration Park will be established to enable and grow private sector participation in space exploration, support commercial space transportation, and promote commercial development of technologies for application in space and on Earth.[92]

Non-NASA use of KSC's Shuttle Landing Facility (SLF) increased during the last year. In February 2006, the SLF was used by the GlobalFlyer airplane for a flight that set a new world record for the longest flight made by any aircraft.[93] NASA and ZERO-G Corporation signed an agreement in April 2006 that will allow ZERO-G to conduct up to 280 weightless flights annually in its modified Boeing 727-200 aircraft from the SLF.[94] In September 2006, NASA issued a request for information from prospective commercial and other non-NASA users of the SLF to support an environmental assessment of commercial suborbital and orbital spaceflight, support, and special purpose aviation, and other compatible uses of the SLF.[95]

Reagan Test Site

Located on 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 (MRTFB). The advantages of RTS include its strategic location, allowing launch in virtually all azimuths, unique instrumentation, and ability 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. As a U.S. Army DoD MRTFB, RTS receives annual federal funding in addition to direct cost reimbursement from customers.

Kwajalein Island

A new launch pad was constructed on Omelek Island in 2006 with funding by SpaceX to support their space launch missions. The Army began deployment of a fiber connection to the continental United States for mission support at the Huntsville Space Operation Control Center and Mission Control Center. Completion of the fiber connection is projected for mid-fiscal year 2008.[96]

With nearly 40 years of successful support, RTS provides a vital role in the research, development, and test and evaluation effort of America's missile defense and space programs. At least 17 organizations, representing the military, academia, civil government, and commercial interests, use RTS.[97] Orbital Sciences, SpaceX and the MDA conduct launch operations from RTS. SpaceX's first launch in March 2006 was unsuccessful. A Pegasus XL launch is scheduled from Kwajalein in the near future.[98]

Vandenberg Air Force Base

VAFB

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 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 ballistic activities for the West Coast. Most U.S. satellites destined for near-polar orbit launch from the Western Range at VAFB. The 30th Space Wing Western Range Operations Control Center provides flight safety, weather, scheduling, instrumentation control, vehicle designation information, and tracking data to and from inter- and intra-range sensors in real or nearly real-time for ballistic and space launch support. Range tracking capabilities extend over the Pacific Ocean as far west as the Marshall Islands. Boundaries to the north stretch as far as Alaska and as far south as Central America. Vandenberg is host to the 14th Air Force Headquarters and the Joint Functional Component Command, Space.

Infrastructure used for space launches at VAFB includes a 4,500-meter (15,000-foot) runway; boat dock; rail lines; launch, booster and 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. Vandenberg Air Force Base 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 U.S. Air Force, DoD, NASA, MDA and various private industry contractors. Vandenberg is 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. For the development of launch infrastructure for the EELV Program, VAFB has partnered with Boeing and Lockheed Martin.

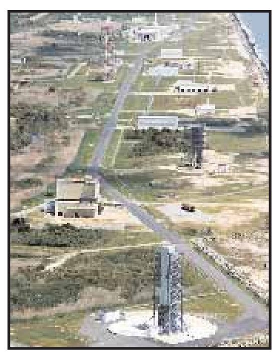
Boeing has renovated SLC-6 from a Space Shuttle launch pad into an operational facility for Delta 4. Construction at SLC-6 has included enlarging the existing mobile service tower and completing the construction of the West Coast Horizontal Integration Facility, where the Delta 4 is assembled.

Lockheed Martin converted 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. A crane capable of lifting 20 tons was replaced with one that can lift 60 tons.

Current space launch vehicles supported by VAFB include Delta 2, Delta 4, Atlas 5, Taurus, Minotaur, Pegasus XL, and Falcon 1. Vandenberg Air Force Base completed an 11-for-11 launch record during fiscal 2006.[99] NASA operates SLC-2, from which Boeing Delta 2 vehicles are launched. The first launch of a Delta 4 from SLC-6 occurred in June 2006. A second successful launch occurred in November 2006. Lockheed Martin is currently completing pathfinder operations in anticipation of a first launch in April 2007. Orbital Sciences's Taurus is launched from 576-E. Pegasus XL vehicles are processed at Orbital Sciences's facility at VAFB then flown to various worldwide launch areas. Vandenberg supports numerous ballistic programs, including Minuteman and numerous MDA test and operational programs.

Vandenberg Air Force Base has active partnerships with private commercial space organizations in which VAFB provides launch property and launch services. The private companies use the government or commercial facilities to conduct launch, payload, and booster processing work. Vandenberg houses three commercially owned complexes: Boeing's Horizontal Integration Facility, Spaceport Systems International's California Spaceport and Payload Processing Facility, and Astrotech's Payload Processing Facility.[100]

Wallops Flight Facility


Wallops Flight Facility

The predecessor of NASA, the National Advisory Committee for Aeronautics, or NACA, established an aeronautical and rocket test range at Wallops Island, Virginia, in 1945. Since then, over 16,000 rocket launches have taken place from the WFF, which is operated for NASA by the Goddard Space Flight Center, Greenbelt, Maryland.

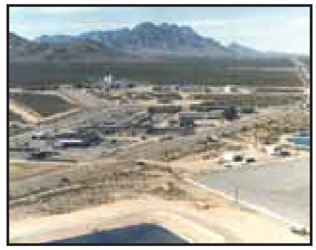
Wallop's primary mission is to serve as a research and test range for NASA, supporting scientific research, technology development, flight testing, and educational flight projects. WFF, however, also heavily supports the DoD and commercial industry with flight projects ranging from small suborbital vehicles to orbital launch vehicles. In addition to rockets, WFF's integrated Launch Range and 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.

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 launchers, 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.

Wallops continues a significant range modernization and technology program, begun in 2002. 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.[101] In early 2007, a class-100,000 clean room will be operationally certified within Bay 1 of the Payload Processing Facility. A new project support facility is nearly completed, providing auditorium capabilities for large gatherings including pre-mission reviews and observation of the launch.[102] WWF is completing its new engineering facility, which will include laboratories.[103] The initial operational capabilities of the Wallops mobile Liquid Fueling Facility will be ready in the spring of 2007.

During 2006, WFF's Research Range supported 30 rocket tests. WFF is heavily engaged in supporting both DoD and commercial interests in the emerging small ELV community, such as those supported by the DARPA Falcon program. WFF successfully supported the launch of the U.S. Air Force and NASA TacSat-2 launch in December 2006, and plans to support the TacSat-3 launch in November 2007, and the U.S. Air Force and NASA NFIRE launch in April 2007.

White Sands Missile Range


White Sands Missile Range

Once exclusively military, White Sands Missile Range (WSMR) today attracts other government agencies, foreign nations, and private industry to its world-class test facilities. The largest overland test range in America, WSMR is operated by the U.S. Army, used by the Army, Navy, Air Force, Marine Corps, and MDA; and home to the NASA White Sands Test Facility. Situated 26 kilometers (16 miles) northeast of Las Cruces, New Mexico, this range covers 8,100 square kilometers (3,100 square miles).

Since establishment in 1945, the range has fired more than 44,500 missiles and rockets. Almost 1,200 of those were research and sounding rockets. WSMR has seven engine test stands and precision cleaning facilities, including a class-100 clean room for spacecraft parts. After KSC and EAFB, White Sands is the Space Shuttle's tertiary landing site. This landing site consists of two 11-kilometer (6.8 mile) long, gypsum-sand runways.[104] 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 state-of-the-art networking, computing, and communications for effective interaction between test operations and customers.

In 2002, the U.S. Army, WSMR, and state of New Mexico signed a Memorandum of Agreement supporting the development of the Southwest Regional Spaceport, which was renamed Spaceport America in 2006. WSMR provided range support for the first rocket launch from Spaceport America in October 2006. Initially, WSMR will provide a diversity of support services for Spaceport America, ranging from flight safety, radar, optical tracking, airspace and ground space for touchdown and recovery.

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 and interest in hosting RLV operations. Tables 5a and 5b describe specific efforts to establish non-federal spaceports, which are in various stages of development.

Cecil Field Spaceport

Originally developed as a naval air station with one 3,810 x 60-meter (12,500 x 200-foot) runway and one 1,160-meter (3,800-foot) runway, Cecil Field was proposed for closure by the Base Realignment and Closure (BRAC) process in 1993. Five years later, based on the recommendation of the Base Reuse Commission, JAA took ownership of 3,240 hectares (8,000 acres), including the runways, hangars, and support infrastructure and has operated the airport for maintenance and repair operations, general aviation activity, and limited military operations. The airport was identified as a potential launch site in the feasibility study of a Florida Commercial Spaceport. The JAA is pursuing a launch site operator's license and is conducting the environmental assessment needed before the issuance of the license. This environmental assessment began in 2006.

Cecil Field Aerial View

Table 5a: Proposed Non-federal Spaceports Infrastructure and Status

Spaceport	Location	Owner/Operator	Launch Infrastructure	Development Status
Cecil Field Spaceport	Jacksonville, Florida	Jacksonville Aviation Authority	One 3,810 x 60-m (12,500 x 200-ft) runway, three 2,440-m (8,000-ft) runways, 175 buildings totaling 270,000-m^2 (2.9 million-ft^2), 8 aircraft hangars, operating air traffic control tower, warehouse, industrial and general use space totaling more than 40,000-m^2 (425,000-ft^2) and general office and support facilities of over 21,000-m^2 (225,000-ft^2).	An environmental assessment for spaceport operations is in process with a final draft expected at the end of January 2007.
Chugwater Spaceport	Platte County, Wyoming	Frontier Astronautics	No complete infrastructure at this time.	Three launch pads and a 2,225,000-n (500,000-ft·lbf) flame trench are being refurbished. Environmental assessment for site approval is in progress.
Gulf Coast Regional Spaceport	Brazoria County, Texas	To be determined	Road, suborbital launch platform, and launch control facility.	The Gulf Coast Regional Spaceport Development Corporation has proposed constructing a spaceport in Brazoria County, Texas, 80-km (50-mi) south of Houston. FAA suborbital launch site licensing process is underway.
South Texas Spaceport	Willacy County, Texas	Willacy County Development Corporation for Spaceport Facilities	Road, as an extension to the road to the airport, 6-in water line with fire hydrant, 18 x 25 x 5-m (60 x 80 x 16-ft) metal building with concrete slab.	The final Texas Spaceport site has been selected, and it is in Port Mansfield, near Charles R. Johnson Airport. Suborbital rockets have been launched near the proposed site.
Spaceport Alabama	Baldwin County, Alabama	To be determined	No infrastructure at this time.	The master plan Phase 1 has been completed and Phase 2 is under development. The Spaceport Alabama master plan is expected to be completed by the end of 2007. 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.

Table 5b: Proposed Non-federal Spaceports Infrastructure and Status

Spaceport	Location	Owner/Operator	Launch Infrastructure	Development Status
Spaceport America	Upham, New Mexico	New Mexico Spaceport Authority	Temporary infrastructure, including a launch pad, weather station, rocket motor storage facilities and trailers.	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. Construction to begin in third quarter of 2007. Environmental and business development studies conducted. First launch took place in September 2006.
Spaceport Sheboygan	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. Wisconsin Aerospace Authority legislation was signed into law in 2006.
Spaceport Washington	Grant County International Airport, Washington	Port of Moses Lake	4,100-m (13,452-ft) main runway and a 3,200-m (10,500-ft) crosswind runway.	A 12,100 ha (30,000-a) 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-m (100 x 100-ft) scraped and level staging area. Broadband Internet on site, controlled fenced access, and a 1,295-km^2 (500 mi^2) recovery area. Airport has 5 runways (2,286 x 30-m, or 7,500 x 100-ft) with hangar space.	Development plan approved by State of Texas in 2005. State has provided $175,000 in 2005 for planning studies. Future infrastructure plans include 1,070-m (3,500-ft) runway, static engine testing facility, and balloon hangar.

The infrastructure of this airfield provides an existing facility conducive to spaceport operations, including one 3,810-meter (12,500-foot) runway, three 2,440-meter (8,000-foot) runways, 175 buildings totaling 270,000 square meters (2.9 million square feet), eight aircraft hangars, operating air traffic control tower, warehouse, industrial and general use space totaling more than 40,000 square meters (425,000 square feet), and general office and support facilities of over 21,000 square meters (225,000 square feet). During 2006, JAA continued to maintain and upgrade the runways, taxiways, lighting systems, and other infrastructure. The 3,810-meter (12,500-feet) runway, together with the location in a sparsely populated area and the proximity to the coast make this site attractive for future commercial space activities.

The following projects are highlights of the plans for 2007: development of additional taxiway and apron area, construction of an access road, approach lighting system for runway 9R/27L, parking rehabilitation, development of a security training facility, perennial comprehensive, and environmental planning projects. The plan is for Cecil Field to use facilities that currently exist to support horizontal launch vehicles. This includes facilities that could be used for crew and passenger training. Because of the quality of the existing facilities, space operations could begin at Cecil Field with minimum infrastructure costs to the launch operator. As the requirement for additional launch and training facilities develop, Cecil Field has the land and infrastructure in place to accommodate increasing demand. Additionally, the Florida Community College at Jacksonville's Aviation Center of Excellence is presently establishing an Aerospace Resource Center to educate and develop personnel to support the commercial space industry.[105]

Chugwater Spaceport

Chugwater Spaceport aerial view

The Chugwater Launch site was originally an Atlas E Missile Base, outside of Chugwater, Wyoming, built in 1960 and decommissioned in 1965. Designed to store and launch a complete Atlas E ICBM, the facilities are designed with many special amenities for rocketry. In March 2006, Frontier Astronautics bought the property and began renovation to use it as a launch site.

Since the last change in ownership, maintenance work has been performed to get original military equipment operational. During 2006, three horizontal engine tests of a LOX and kerosene Viper™ 33,360-newton (7,500-pound-force) engine took place at the Chugwater site. The tests were possible because Frontier Astronautics obtained an exception to the countywide fire ban. So far, almost $500,000 has been invested in the site, all from private sources. Although currently there is no official development plan for the spaceport, the state of Wyoming is very interested in developing a spaceport. Frontier Astronautics is in the process of submitting a proposal for assistance. No direct financial support is expected from the state, but state officials anticipate providing a small business loan in 2007.

Plans for future infrastructure include a functioning 2,225,000-newton (500,000-pound-force) vertical test stand for engine testing, a horizontal engine test stand, up to three vertical launch pads, on-site machine shop, and shooting range. The planned configuration of the spaceport launch site is vertical launch pads with water deluge system.[106]

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 identified undeveloped land and leased 81 hectares (200 acres) from the private owner, Dow Chemical Corporation.

The GCRSDC has in place a phased plan for development and is currently focused on short-term goals of creating infrastructure, securing an FAA Class III suborbital license, and marketing the facility to potential users for unguided suborbital missions. Phase I and Phase II of the suborbital licensing process have been completed. Phase III is currently in progress, with the main focus on an environmental assessment and flight safety analysis. A draft of the environmental assessment is planned to be submitted to FAA in 2007. The development plan also includes preparation of the application for beginning the licensing process in pursuit of an orbital license at a site to be determined.

The state of Texas approved the current scope of work, and in March 2006, the Brazoria County Commissioners approved interlocal agreements with the GCRSDC to build a launch pad and roads. The site plans include an access road from the U.S. Fish and Wildlife road to the launch area, culverts with stabilizing material for a crushed concrete entrance and 5-meter (16-foot) gate at the property line, a 6 x 6 meter (20 x 20 foot) launch pad surrounded by a concrete area, a parking area, and 1,200 linear meters (4,000 linear feet) of wire fencing.[107] During 2006, the GCRSDC completed the entryway to the site and constructed a gravel access road, with in-kind support from Brazoria County.

Local and state governments have allocated funds for the development of the Gulf Coast Regional Spaceport since 1999, financing the site selection, the safety analysis, and the studies determining the necessary infrastructure. The last time funding was received was in 2005, when the state of Texas awarded the GCRSDC a grant for $325,000, which was used to initiate the licensing procedure.

South Texas Spaceport

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. Willacy County Development Corporation for Spaceport Facilities is the owner of the spaceport.

The designated spaceport site is a 405,000 square meters (0.16 square miles) undeveloped site in Port Mansfield, adjacent to the Charles R. Johnson Airport, 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.

During 2006, almost $200,000, including in-kind contributions, was invested in building new infrastructure. All the new developments in 2006 happened with the assistance of government funding. Preliminary spaceport construction was completed. A new road was installed, an extension to the road to the airport. A 15-centimeter (6-inch) water line with fire hydrant was added to the new 18 x 25 x 5 meter (60 x 80 x 16 feet) metal building with concrete slab. The launch barge for all launches still needs to be purchased.

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 Aerospace Development Center of Alabama located in Anniston, Alabama. The Spaceport Alabama master planning Phase 1 is now complete, while Phase 2 has commenced and is still under development. Upon completion of the Spaceport Alabama master plan, which is expected to be done by the end of 2007, 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 green field 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 (medium Earth orbit), and GEO.[108]

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.

Spaceport America

The State of New Mexico continues to make significant progress in the development of Spaceport America, known as Southwest Regional Spaceport prior to July 2006. In December 2005, Richard Branson decided to establish the headquarters of the Virgin Galactic spaceline in New Mexico and use Spaceport America as its primary operating base. He also entered a partnership with the State of New Mexico to build the spaceport. While the state would build the spaceport, Virgin Galactic would sign a 20-year lease agreement with annual payments of $1 million for the first 5 years. The state government would pay about half of the construction cost, with the difference to come from local and federal governments.[109]

Spaceport America Launcher Installation

Spaceport America is being developed for use by private companies and government organizations conducting space activities and operations. In March 2006, New Mexico passed a bill that creates one entity, the New Mexico Spaceport Authority, to oversee the spaceport. An FAA launch site license is expected in the third quarter of 2007. Thus, the state owns and operates the spaceport and will lease the facilities to the users. In January 2006, New Mexico state officials signed an agreement that gives the planned spaceport north of Las Cruces access to nearly 6,070 hectares (15,000 acres) of state trust land to begin developing the site.[110] The spaceport is a 70-square-kilometer (27-square-mile) parcel of open land in the south central part of the state, near the desert town of Upham, 72 kilometers (45 miles) north of Las Cruces and 48 kilometers (30 miles) east of Truth or Consequences, at approximately 1,430 meters (4,700 feet) above sea level. This location was selected for its low population density, uncongested airspace, and high elevation.[111]

During the past year, temporary facilities added to the site include a launch pad, a weather station, rocket motor storage facilities and trailers. This infrastructure is worth $450,000; with funding from private and government sources. Major components of the proposed Spaceport America also include two launch complexes, a landing strip, an aviation complex, and support facilities. The spaceport has an officially approved development plan that includes beginning construction in third quarter of 2007, and having a full-fledged spaceport to support vertical launches, vertical landings, and horizontal landings by 2010. Currently, DMJM/AECOM, an architecture and engineering contractor, is designing the facilities with inputs from the spaceport users, as the final configuration will be customer driven.[112] New Mexico lawmakers have approved the allocation of $110 million for the development of the spaceport, as direct financial support, starting in 2007.

New Mexico provides 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 state has also passed legislation that allows counties and municipalities to impose, upon voter approval, a regional spaceport gross receipt tax, in increments of one-sixteenth percent, not to exceed one-half percent.[113]

The first launch from the spaceport took place on September 25, 2006, when UP Aerospace launched an amateur class vehicle. The commitment in building the spaceport, the recent activities there, together with the state incentives to locate space-related businesses in New Mexico have made the state an attractive location for rocket builders, such as Starchaser Industries, the annual X Prize Cup, and the Rocket Racing League.

Spaceport Sheboygan

Rocket Launch
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, Incorporated, 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 2006. Rockets for Schools is a firmly established 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. In May 2006, under the Rockets for Schools program, more than 50 rockets were launched off of the pier. Additionally, some structures were removed to clear space for the construction of a proposed mission control and education center. Past construction has been financed through municipal, state, and federal agencies. The state of Wisconsin contributed to the development of the spaceport with site preparation of coastline and access roads. No new infrastructure was constructed during 2006.

Plans for developing additional launch infrastructure are ongoing. Future projects include adding orbital launch capabilities for RLVs, including a horizontal and vertical launch site. Spaceport developers are in the process of creating a development plan. Legislation for the creation of the Wisconsin Aerospace Authority (WAA) was signed into law in 2006. The legislation authorizes the WAA to develop spaceports, spacecraft, and other aerospace facilities in Wisconsin; provide services for, and allow use of, spaceport and aerospace facilities; promote the aerospace industry in Wisconsin; and provide public-private coordination for the aerospace industry in Wisconsin.[114] In addition to designing, developing, and operating the spaceport, WAA is authorized to sell up to $100 million in revenue bonds.[115]

The spaceport establishment project has several phases. The first phase refers to the development of the Great Lakes Aerospace Science and Education Center at Spaceport Sheboygan and is currently underway. A preliminary business plan for the center has already been developed. The second phase for the project includes proposing legislation for the development and operational plans of the Wisconsin Spaceport. Once the legislation is approved, WAA will conduct site evaluation, feasibility, and environmental impact studies. Project supporters are also in the initial stages of obtaining a FAA launch site license.[116]

Spaceport Washington

Spaceport Washington Aerial View

Spaceport Washington, a public and 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 Air Force Base 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 all classes of RLVs. This airport has a 4,115 x 61-meter (13,503 x 200-foot) main runway and a 3,048 x 30-meter (10,000 x 100-foot) crosswind runway and is certified as an emergency landing site for the Space Shuttle. The spaceport does not have an official development plan yet, but the intended configuration of the spaceport launch site will either be vertical launch and horizontal recovery or horizontal launch and recovery.[117]

An approximately 12,100 hectare (30,000-acre) potential vertical launch site has been identified with multiple owners, both public and private. The spaceport has also established an Aerospace Overlay Zone within the Grant County Unified Development Code. This zone protects 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 depends on launch customers' needs and market responses.[118] At present, Spaceport Washington is seeking launch operators and developing an operations and business plan.[119]

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 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), the payload integration and launch control facilities, and the Pecos County Airport runway (2,300-meters or 7,500 feet) and hangar complex. The site has access to over 11,600 square kilometers (4,500 square miles) of unpopulated land and over 26,000 square kilometers (10,000 square miles) of underutilized national airspace. The West Texas Spaceport is mainly an R&D site for UAVs and suborbital rockets. The primary users of this spaceport will be the operators of unmanned air systems.

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. 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 size of the vehicle) regardless of its speed. For the past two years, Pecos County/West Texas Spaceport Development Corporation has been involved in educational activities, under the framework of Texas Partnership for Aerospace Education, to promote and support academic programs in aero-science and rocketry.

In February 2002, the Texas Aerospace Commission awarded a $500,000 contract to the West Texas Spaceport. In June 2002, the U.S. Air Force 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 awarded the Pecos County/West Texas Spaceport Development Corporation $80,000 for 2003. During 2005, the Texas legislature passed a bill creating the Emerging Technology Fund. This fund offers grants and tax breaks to companies involved in promoting new technologies. The Pecos County/West Texas Spaceport Development Corporation falls under this category and has benefited from grants from this fund.

During 2005, the following spaceport infrastructure was added: an industrial strength concrete pad, a 30 x 30 meter (100 x 100 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. This plan targets the early stage R&D projects. Flight activity included launches of the NASA Dryden DART suborbital rocket, the Texas Partnership for Aerospace Education series of suborbital rocket tests, UAV tests done by Lockheed Martin, tests of the Air Force Battlelab Near Space Maneuvering Vehicle and UAV tests for Air Force Space Battlelab. More UAV testing took place toward the end of 2006.

Future infrastructure plans include the development of a privately funded 1,000-meter (3,500-foot) runway, a static engine test facility, and a hangar for balloon and wind sensitive activities. Other projects pursued by the Pecos County/West Texas Spaceport Development Corporation include the Blacksky DART program, intended to characterize the performance of an innovative aerospike nozzle on a solid rocket motor.[120]

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