Federal Aviation Administration

2008 U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports

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List of Acronyms

AADC	Alaska Aerospace Development Corporation
ACES	Air Collection and Enrichment System
AFB	Air Force Base
AGL	Above Ground Level
AFRL	Air Force Research Laboratory
ALV	ATK Launch Vehicle
ARCTUS	Advanced Research and Conventional Technology Utilization Spacecraft
AST	Office of Commercial Space Transportation (within the FAA)
ATK	Alliant Techsystems
ATV	Automated Transfer Vehicle
AWOS	Automated Weather Observing System
BLS	Boeing Launch Service
BRAC	Base Realignment and Closure
BSC	Benson Space Company
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
CSLAA	Commercial Space Launch Amendments Act
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
ESA	European Space Agency
FAA	Federal Aviation Administration
FALCON	Force Application and Launch from CONUS
FAST	Fully-Reusable Access to Space Technology
FASTT	Freeflight Atmospheric Scramjet Test Technique
GEM	Graphite-Epoxy Motor
GEO	Geosynchronous Earth Orbit
GPS/INS	Global Positioning System/Inertial Navigation System
GSC	Garvey Spacecraft Corporation
GSLV	Geosynchronous Satellite Launch Vehicle
GTO	Geosynchronous Transfer Orbit
HTHL	Horizontal Takeoff, Horizontal Landing
HTP	High-Test Peroxide
HTPB	Hydroxyl Terminated Polybutadiene
HTR	Hybrid Test Rocket
HTS	Horizontal Test Stand
HX	Hydrocarbon X
HYSR	Hybrid Sounding Rocket
ICBM	Intercontinental Ballistic Missile
IPD	Integrated Powerhead Demonstration
IPF	Integrated Processing Facility
ISS	International Space Station
ISRO	Indian Space Research Organization
ITAR	International Traffic in Arms Regulations

JAA	Jacksonville Aviation Authority
LAS	Launch Abort System
KLC	Kodiak Launch Complex
KSC	Kennedy Space Center
LAP	Launch Assist Platform
LAS	Launch Abort System
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
MTA	Mojave Test Area
NASA	National Aeronautics and Space Administration
NG-LLC	Northrop Grumman Lunar Lander Challenge
NLV	Nanosat Launch Vehicle
NPRM	Notice of Proposed Rulemaking
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
PSLV	Polar Satellite Launch Vehicle
PWR	Pratt & Whitney Rocketdyne
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
SLV	Small Launch Vehicle
SSI	Spaceport Systems International
SS/L	Space Systems / Loral
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
USAF	United States Air Force
VAB	Vehicle Assembly Building

VAFB	Vandenberg Air Force Base
VaPaK	Vapor Pressurization
VTS	Vertical Test Stand
VCSFA	Virginia Commercial Space Flight Authority
WAA	Wisconsin Aerospace Authority
WIRED	Workforce Innovation in Regional Economic Development
WFF	Wallops Flight Facility
WSMR	White Sands Missile Range
XA	eXtreme Altitude

Introduction

2007 was a year of continued steady progress across the broad spectrum of technology sectors that together constitute the commercial space industry. Worldwide orbital launches occurred in numbers closely mirroring those of the previous two years, demonstrating that the industry's recovery from the sharp downturn in launch activity earlier in the decade has stabilized. Additionally, development and testing of new expendable and reusable launch vehicles continued, with several vehicles taking considerable steps toward operability.

The space tourism industry also came into greater definition in 2007. Virgin Galactic surpassed its mark of 100 committed suborbital spaceflight passengers, and had garnered some $31 million in revenues from ticket sales as the year closed. Other companies and private financiers funded exploration of alternative space tourism vehicle and spaceport concepts. And in April 2007, American software developer Charles Simonyi became the fifth orbital space tourist to visit the International Space Station (ISS) aboard a Soyuz flight sponsored by Space Adventures Ltd.

Finally, commercialization initiatives proceeded apace. Following its award of $500 million to Space Exploration Technologies (SpaceX) and Rocketplane Kistler (RpK) in 2006 for the agency's Commercial Orbital Transportation Services (COTS) program, NASA in 2007 withdrew the $174 million remaining in its award to RpK and began a process of recompeting it among other vehicle developers. New Mexico again hosted the X PRIZE Cup, where private vehicle developers competed a second time for X PRIZE Foundation and NASA Centennial Challenges awards. And the United States Department of Defense (DoD), via a host of initiatives, continued to fund development of new vehicle families able to launch quickly and inexpensively, as well as be 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 2007. It showcases current and planned U.S. commercial or commercially-oriented activities. It also addresses space competitions, reusable launch vehicles (RLVs), expendable launch vehicles (ELVs), reentry vehicles and in-space technologies, enabling technologies such as propulsion and launch configurations, the evolving array of U.S. spaceports, and new developments in the regulatory arena.

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

Space Competitions

In September 2007, a significant new international space prize competition was announced encouraging the private exploration of the Moon. The Google Lunar X PRIZE was organized by the X PRIZE Foundation with sponsorship from Google, along with strategic partnerships with SpaceX, the SETI Institute, the Saint Louis Science Center, and the International Space University.

The second X PRIZE Cup took place October 27-28, 2007, at Holloman Air Force Base's Air and Space Expo, near Alamogordo, New Mexico. The Northrop Grumman Lunar Lander Challenge was held, featuring several rocket flights by Armadillo Aerospace under an FAA-issued experimental permit. Like the competition held in 2006, none of the registered participants successfully completed the challenge criteria. However, promising technologies were flown and static displays provided interactive education for the general public.

In 2007, the first prize money was awarded for the Centennial Challenge program: one prize for $200,000 was awarded for space technology (astronaut gloves). Although participants fell short in other Centennial Challenges they attempted, several were determined to try again in 2008, and their efforts showed promising technological progress.

Expendable Launch Vehicle Industry

In 2007, U.S. ELVs—with one notable exception—maintained launch tempos comparable to the year prior. The Atlas V, Delta II, Delta IV, Minotaur I, Pegasus XL, and other ELVs conducted numerous launches, all successful. The Taurus vehicle did not launch in 2007, but two Taurus launches are scheduled for 2008. The Sea Launch Zenit-3SL booster—a major commercial launch provider—suffered a launch failure in January 2007 that derailed its use for the remainder of the year. However, the Zenit-3SL is expected to return to flight and fully resume its commercial launch tempo in 2008.

In addition, UP Aerospace conducted the first successful commercial launch of its SpaceLoft XL suborbital rocket. The launch was the first successful mission launched from New Mexico's Spaceport America.

Several companies continued to develop new ELV concepts in 2007, including the Alliant Techsystems (ATK) Launch Vehicle; 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 (GSC); Eagle SLV by Microcosm; QuickReach by AirLaunch LLC; Z-1 by Zig Aerospace, LLC; and the Zenit-3SLB vehicle being developed by Sea Launch. Most of these designs focus on the small payload market.

Additionally in 2007, NASA further refined plans for the Ares I and Ares V vehicles, which will leverage Space Shuttle and Apollo-era technologies toward future manned and unmanned missions. In July, NASA awarded Pratt & Whitney Rocketdyne a $1.2-billion contract to develop the Ares I upper stage engine, and in August 2007, the agency selected Boeing to build the Ares I upper stage itself. Planning for the Ares V was ongoing, with detailed technical specifications for the vehicle yet to be announced.

Reusable Launch Vehicle Industry

Several RLV efforts enjoyed notable successes in 2007. On the heels of the first FAA-permitted flight of Blue Origin's New Shepard rocket in late 2006, the company performed two follow-on test flights on March 22 and April 19, 2007. Additionally, the second Falcon 1 launch, designated Demo Flight 2, took place on March 20, 2007. Although the vehicle failed to reach orbit because of an upper stage control anomaly causing the engine to shut down prematurely, SpaceX has taken several steps to resolve the problem, and a third Falcon 1 flight is expected in 2008.

Armadillo Aerospace received an experimental permit for its MOD-1 vehicle in 2007. Under this permit, on October 20, MOD-1 performed a low-altitude flight test at the Oklahoma Spaceport to demonstrate it was capable of performing the flight profile needed to win Level One of the Lunar Lander Challenge. MOD-1 then made four flights at the 2007 X PRIZE Cup in an effort to win the competition. The vehicle successfully flew the first leg of the Level One challenge on the afternoon of October 27, but during the return suffered a "hard start" of its engine causing a shut down as the vehicle hovered over the landing pad. Despite this minor setback, Armadillo plans to continue test flights in 2008.

Other companies pursued ongoing tests of their respective RLVs in 2007. Among the highlights, Masten Space Systems' XA 0.1 began tethered flight tests, with larger prototype, the XA 0.2, currently under development; and Rocketplane Global unveiled a new design for the Rocketplane XP suborbital vehicle.

Reentry Vehicles and In-Space Technologies

The NASA Vision for Space Exploration, along with the planned 2010 retirement of the Space Shuttle, has prompted the need for new reentry vehicles and in-space technologies to support future manned and unmanned missions. To maintain mission capability after the Shuttle is retired, NASA is developing the Orion Crew Exploration Vehicle to carry people and pressurized cargo into space. At the end of missions, Orion will also serve as the atmospheric reentry vehicle. It will reenter the atmosphere using a newly-developed thermal protection system. Unmanned abort testing of this reentry vehicle is slated to begin in 2008.

Among notable other initiatives in this technology sector, Bigelow Aerospace followed its successful 2006 Genesis I mission with a second orbital habitat demonstration mission, Genesis II, in 2007, as well as preparation of the larger Galaxy and Sundancer inflatable modules. Galaxy will be a ground-tested module, though it was originally planned to be launched into orbit during 2008.

Enabling Technologies

Department of Defense (DoD) needs remained a primary driver of enabling technology development in 2007. In July 2007, for example, DARPA and the USAF jointly agreed to fund Phase 2C of AirLaunch LLC engine tests at a value of \$7.6 million. These Vapor Pressurization (VaPak) upper stage engines for the AirLaunch QuickReach Small Launch Vehicle (SLV) would facilitate delivery of a 450-kilogram (1,000-pound) payload to low Earth orbit (LEO) for \$5 million per launch with a response time of less than 24 hours—an application useful to operationally responsive space and other defense needs.

In addition, a large 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, new launch methodologies such as air launch, and other technologies and techniques. These enabling technologies can be leveraged for a wide variety of defense and other space access applications.

Spaceports

In 2007, federal and non-federal spaceports alike sought to expand their capabilities to entice an emerging responsive and suborbital space tourism market. These spaceports continued to carry out launches at similar tempos as in recent years while implementing infrastructure improvements as funding allowed and exploring whether and how to position themselves within the commercial marketplace.

Regulatory Developments

2007 was also a year of ongoing regulatory enhancements. The FAA continued to refine its regulations in three primary areas: private human spaceflight, experimental launches, and amateur rockets.

Significant 2007 Events

January 11: China demonstrates a major new military space capability by successfully testing an anti-satellite weapon that destroys the aging Chinese weather satellite Fengyun 1C. The test creates considerable orbital debris and draws formal protests from the United States, Australia, Canada, Japan, South Korea, and other nations.

January 30: A Sea Launch Zenit-3SL rocket explodes upon liftoff, destroying the vehicle and its payload, the NSS 8 communications satellite, as well as damaging the Odyssey Launch Platform. Russian and Ukrainian authorities identify a foreign object in an engine turbopump as the likely cause of the failure.

February 21: NASA Ames Research Center and space tourism company Virgin Galactic sign a memorandum of understanding to cooperate on developing various technologies including spacesuits, thermal protection systems, hybrid propulsion systems, and hypersonic vehicles.

March 20: Space Exploration Technologies (SpaceX) conducts the second launch of its Falcon 1 rocket from Kwajalein Atoll in the Pacific Ocean. The vehicle lifts off successfully and climbs to an altitude of approximately 300 kilometers (183 miles). However, at five minutes into the flight the rocket's second stage experiences a roll control anomaly and fails to achieve orbit. SpaceX concludes that the anomaly caused propellants to centrifuge away from tank outlets, leading the engine to shut down prematurely. Although the rocket does not reach orbit, SpaceX considers the flight a success that demonstrated the viability of about 90 percent of the technologies used in the vehicle.

April 3: Voters in New Mexico's Doña Ana County approve a sales tax increase designed to raise an estimated $49 million toward funding Spaceport America, the future headquarters of Sir Richard Branson's Virgin Galactic suborbital space tourism company.

April 7: The Soyuz ISS 14S mission lifts off from Baikonur in Kazakhstan carrying the fifth orbital space tourist to the International Space Station (ISS). Charles Simonyi, a software architect formerly with Microsoft, spends 13 days in space in a trip organized by the space tourism company Space Adventures, Ltd. before returning safely to the Earth on April 21.

April 23: India conducts its first commercial launch as a Polar Satellite Launch Vehicle (PSLV) lifts off from Satish Dhawan Space Centre carrying AGILE, an Italian astrophysics satellite. The launch is marketed by Antrix, the commercial arm of the Indian Space Research Organisation (ISRO).

April 28: UP Aerospace conducts the first successful commercial launch of its Spaceloft XL suborbital rocket, lofting a Celestis capsule carrying the cremains of actor James Doohan (the character "Scotty" from Star Trek), astronaut Gordon Cooper, and others to an altitude of 115 kilometers (72 miles) before coming down at White Sands Missile Range. It is the first successful mission launched from Spaceport America.

May 22: The European Commission and the European Space Agency (ESA) formally adopt the first official European Space Policy, a landmark policy document resulting from nearly three years of European Space Council meetings involving consultation with 29 member and observer states. It expresses that space will play an increasing role in the security and prosperity of Europe, that European space assets must be protected from disruption, and that Europe must maximize its return on investment in space.

June 7: A Boeing Delta II launches the COSMO-SkyMed 1 remote sensing satellite from Vandenberg Air Force Base (VAFB).

July 20: Northrop Grumman Corporation, which had previously held a 40 percent stake in Scaled Composites, LLC, announces its acquisition of the Mojave, California-based developer of the SpaceShipOne vehicle that captured the Ansari X Prize in 2004. Both companies state the acquisition will have no effect on Scaled Composites' arrangement to provide a fleet of SpaceShipTwo vehicles to Virgin Galactic.

July 26: A nitrous oxide flash explosion at Mojave Air and Space Port, California, kills three Scaled Composites employees and injures three others. The accident prompts Mojave Air and Space Port and Scaled Composites officials to review preventive safety procedures at the launch facility.

September 6: A Proton rocket carrying the Japanese communications satellite JCSAT 11 does not reach orbit when the booster's second stage fails to separate, causing it to crash in Kazakh territory downrange from the Baikonur launch site. An investigation by a Russian State Commission concludes the failure was caused by a defective cable that prevented the firing of the explosive bolts used in stage separation. The Proton vehicle returns to flight on October 26.

September 13: The X PRIZE Foundation and the Internet search engine company Google unveil the $30-million Google Lunar X PRIZE competition. Under the terms of the competition, Google will award $20 million to the first company to develop a lunar rover that can soft-land on the Moon, rove at least 500 meters, and return a series of high-resolution images and videos. A $5-million prize will be awarded to the second company to achieve the feat. The remaining $5 million will fund bonus prizes, such as discovering lunar water ice. The X PRIZE Foundation will administer the competition, whose cash prize expires at the end of 2014.

September 18: A Boeing Delta II launches the WorldView 1 remote sensing satellite from VAFB.

October 18: NASA terminates an existing agreement with Rocketplane Kistler (RpK) to help fund development of a reusable launch vehicle after the 30-day notice of termination the agency had given RpK in September expires. The company was one of two to win Commercial Orbital Transportation Services (COTS) demonstration awards. RpK had taken over the development of the K-1 vehicle originally proposed by Kistler Aerospace, but had missed several milestones in its agreement due to the company's difficulty raising an estimated $500 million from the private sector. NASA announces plans to hold a competition to award the remaining money in the RpK award, $174.7 million, with results to be announced in 2008.

October 27-28: The 2007 X PRIZE Cup is held at Holloman Air Force Base's Air and Space Expo in New Mexico. An estimated 85,000 people over two days attend this second X PRIZE Cup, an air and space expo conceived to highlight the emerging personal spaceflight industry and stage technology competitions such as the Northrop Grumman Lunar Lander Challenge.

November 6: Striking machinists involved with Space Shuttle operations at the Kennedy Space Center (KSC) reach an agreement with their employer, United Space Alliance, on a new three-year contract providing workers with a substantial portion of the wage increases they had sought and more limited concessions on benefits.

November 22: Russia announces plans for a new spaceport, the Vostochny ("Eastern") cosmodrome, in the Amur region located in the Far East of the country. The precise location of the spaceport will be decided by 2010, with unmanned launches slated to begin from there by 2015, followed by manned missions in 2018.

November 24: European Union (EU) member nations reach an agreement on funding the Galileo satellite navigation system after deciding to divide development of the constellation into six contracts and prohibit any one company from winning more than two of them. The proposal will fund Galileo at €2.4 billion (US$3.5 billion) using unspent agricultural subsidies.

December 6: Odyssey Moon, a newly established international lunar enterprise based in the Isle of Man, announces it will seek the $30-million Google Lunar X PRIZE, making the company the first team to complete registration for entry into the competition.

December 8: A Boeing Delta II launches the Cosmo-Skymed 2 remote sensing satellite from VAFB.

Space Prize Competitions

The U.S. space community has a number of prize competitions that promote the development of commercial spaceflight technology. Various technologies and services are being competed in order to increase the capability of private spacefaring entities to access and operate within suborbital space, orbital space, and beyond. These competitions aim to create commercial space launch services (and other space capabilities) with lower costs, better quality, and more efficient processes than the options currently available. The four sets of currently active prize competitions are the Google Lunar X PRIZE, the X PRIZE Cup, America's Space Prize, and NASA's various Centennial Challenges.

Google Lunar X PRIZE

In September 2007, the X PRIZE Foundation announced a new international space prize competition to encourage the private exploration of the Moon. The Google Lunar X PRIZE calls for privately funded teams to land a robot on the surface of the Moon, explore the surface by traveling at least 500 meters, and return two packages of high-resolution video and imagery (called "Mooncasts") back to the Earth. The first place winner will claim $20 million if the prize is won by the end of 2012, or $15 million if the prize is won in 2013 or 2014. A second place prize valued at $5 million is available for the second team to complete the contest criteria before the end of 2014; it may also be awarded in place of the first place prize if the first team partially completes the mission. Additional bonus prizes worth a total of $5 million will be available for successfully completing certain complex lunar exploration tasks, bringing the total Google Lunar X PRIZE purse to $30 million.[1]

Lunar rover mockup at the introduction of the Google Lunar X PRIZE

The contest will require teams to use a private launch, thereby pushing forward commercial launch vehicle capability and potentially increasing launch demand.

X PRIZE Cup

The X PRIZE Cup is an annual event 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. Thus far, two Cups have been held, plus the "Countdown to the X PRIZE Cup" in 2005. At both Cups, $2 million in prizes have been offered as part of the Northrop Grumman Lunar Lander Challenge, a prize competition funded by NASA's Centennial Challenges program. 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 a vehicle's 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 will not allow for these types of competitions for several years, though other significant activities have taken place at the annual event.

The second X PRIZE Cup took place October 27-28, 2007, at Holloman Air Force Base's Air and Space Expo, near Alamogordo, New Mexico. The Northrop Grumman Lunar Lander Challenge (see the Centennial Challenges section) was held, which featured several rocket flights by Armadillo Aerospace under an FAA-issued experimental permit. Like the competition held in 2006, none of the registered participants successfully completed the challenge criteria, but promising technologies were flown and static displays provided interactive education for the general public.[3]

America's Space Prize

Bigelow Aerospace has proposed a commercial spaceflight competition, America's Space Prize, to develop affordable spacecraft that could service their future space complexes. This prize challenges entities to design a spacecraft without government funding that is capable of carrying passengers into orbit with the eventual goal of transporting humans to Bigelow Aerospace's expandable space habitats. According to the rules, competitors will be required to build a spacecraft capable of carrying a five-person crew to an altitude of 400 kilometers (240 miles) and completing two orbits of the Earth at that altitude. They must then repeat that accomplishment within 60 days. Both flights must carry passengers, and the second flight must carry a crew of at least five. The spacecraft will have to dock with a Bigelow Aerospace space complex or, at a minimum, demonstrate relevant docking capability. In addition, no more than 20 percent of the spacecraft can consist of expendable hardware. With the successful launch and ongoing operation of the Genesis I and Genesis II pathfinder spacecraft, as well as the company's current plans for future habitable complexes, Bigelow Aerospace is aggressively continuing to build demand for the transportation systems outlined in the America's Space Prize competition. The competition deadline is January 10, 2010, with a cash prize of $50 million, funded fully by Bigelow Aerospace.[4]

Centennial Challenges

NASA's Innovative Partnerships Program (IPP) uses Centennial Challenges to advance the development of space technologies through prize competitions, bringing important government encouragement to commercial efforts. Centennial Challenges was previously located within the Exploration Systems Mission Directorate, but was moved to IPP at the beginning of fiscal year 2007. This program creates specialized competitions to stimulate progress on specific technologies related to exploring space and other NASA missions. NASA uses funding outlets beyond the standard procurement process and collaborates with non-profit organizations to sponsor, promote, and operate the competitions. There are seven Centennial Challenges currently active, six of which support space technology. All of these are open for competition between U.S. non-governmental entities. Not all of the competitions deal directly with commercial space transportation technologies, but they do spur technology development for use in future space missions, and can drive the demand for spaceflight. The first award of Centennial Challenges prize money was made in 2007 for space technology. Other Centennial Challenge attempts, while not winning prize money, have shown promising technological progress.[5]

The NASA prize competition that correlates most directly with rocket-powered commercial space transportation is the Northrop Grumman Lunar Lander Challenge (NG-LLC). This competition is administered and executed by the X PRIZE Foundation, who received funding to cover administrative costs from Northrop Grumman in exchange for naming rights of the competition. The rules of the NG-LLC call for a rocket-propelled vehicle with an assigned payload mass to demonstrate its ability to takeoff vertically, fly for a minimum amount of time during which it must reach a certain altitude, travel horizontally to a designated landing area, land vertically at the landing area, and complete a similar return trip within a set timeframe. The flight characteristics are tested at two different difficulty levels that have separate prizes based on increasingly difficult requirements. During the 2007 NG-LLC held at the X PRIZE Cup, Armadillo Aerospace was the only participant to fly a lunar lander concept, though nine teams had originally registered to compete.[6] Armadillo made four flight attempts to win the first-level competition using its MOD-1 vehicle. The team was unable to win the prize money and did not make an attempt at the higher-level difficulty requirements, but the team,

Flight of Armadillo Aerospace's MOD-1 vehicle for the 2007 Northrop Grumman Lunar Lander Challenge as in 2006, showed its technological progress through flight attempts. The total prize money, $500,000 for level one and $1,500,000 for level two, will transfer to 2008 when the challenge will be held again.

The other space-focused Centennial Challenges, not including the Personal Air Vehicle Challenge administered and executed by the Comparative Aircraft Flight Efficiency Foundation, promote future space mission technologies that could increase the likelihood for spaceflight and possibly commercial space transportation. The Astronaut Glove Challenge (run by Volanz Aerospace/Spaceflight America) was won in 2007 by Peter Homer for his glove's best rating in strength, flexibility, and comfort categories.[7] The contest paid $200,000 and will continue in 2008 with a total of $400,000 in prize money. The first two Centennial Challenges ever held, and which will continue in 2008, are the Tether and Beam Power Challenges (conducted by the Spaceward Foundation) encouraging the development of high strength-to-weight materials and wireless power distribution technologies. The 2007 competitions were held at the Space Elevator Games on October 19-21 near Salt Lake City, Utah.[8] There has yet to be a winner of these two challenges, so the prize money will continue to accumulate, increasing in 2008 to $900,000 for each competition. The Regolith Excavation Challenge, conducted in 2007 with four teams but no winner, and Moon Regolith Oxygen Extraction Challenge (both run by the California Space Education and Workforce Institute) are also active. These Challenges have prizes amounting to $750,000 and $1 million, respectively, for future lunar exploration excavation and oxygen extraction technologies.[9] Together, all these competitions are meeting NASA's goals of promoting and publicizing private space technology development through the investment of non-governmental resources, ingenuity, and innovation.

The President's Fiscal Year (FY) 2008 Budget Request asks for $4 million per year for Centennial Challenges for FY 2008 through FY 2012 as a part of the IPP.[10] The FY 2008 omnibus budget bill passed by Congress in December 2007 provides no new funding for Centennial Challenges.[11] Despite the fact that the program's budget was zeroed out in FY 2007 by the continuing resolution and in FY 2008 by the omnibus budget bill, the extant competitions are fully-funded and the prize purses are becoming significantly larger. The funding exists because NASA has not experienced large associated program costs to present, which is a result of administrative and operational cost-shifting through collaborations with non-profit organizations, and because unearned prize money has rolled over from one year to the next. Provided additional appropriations are agreed upon, NASA plans to expand the number of Centennial Challenges, with more competitions dealing with space exploration, science, and transportation.

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. Many of these are designed to launch small satellites at lower costs and quicker than existing vehicles. The third discusses the new launch vehicles being developed exclusively to support the U.S. 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 IV only to government customers. Atlas V, Delta II, Pegasus, and Taurus vehicles are available for commercial and U.S. government launches; the Zenit-3SL is not available for U.S. government missions.

Atlas V – United Launch Alliance

The Atlas V is one of two launch vehicles developed as part of the U.S. Air Force's Evolved Expendable Launch Vehicle (EELV) program in the late 1990s. The Atlas V was developed by the Lockheed Martin Corporation; since December 2006 it has been produced by United Launch Alliance (ULA), a joint venture between The Boeing Company and Lockheed Martin. The Atlas V is made available for commercial launches by Lockheed Martin Commercial Launch Services.

Atlas V

The Atlas V is available in the 400 and 500 series and accommodates 4-meter (13.1-foot) and 5.4-meter (17.6-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. The Atlas V launches out of Cape Canaveral Air Force Station (CCAFS) in Florida and Vandenberg Air Force Base (VAFB) in California.

Since its introduction in 2002 the Atlas V has performed 12 launches. In 2007 four Atlas V launches took place, all non-commercial. On a June 15 launch, the vehicle placed the classified NRO L-30 payload into a lower-than-planned orbit. The divergence from the planned orbit was traced to a leaky fuel valve in the Centaur upper stage that caused the Centaur engine to shut down early. That valve has been replaced with a proven older model.[12] Up to seven Atlas V launches, including one commercial mission, are planned for 2008.

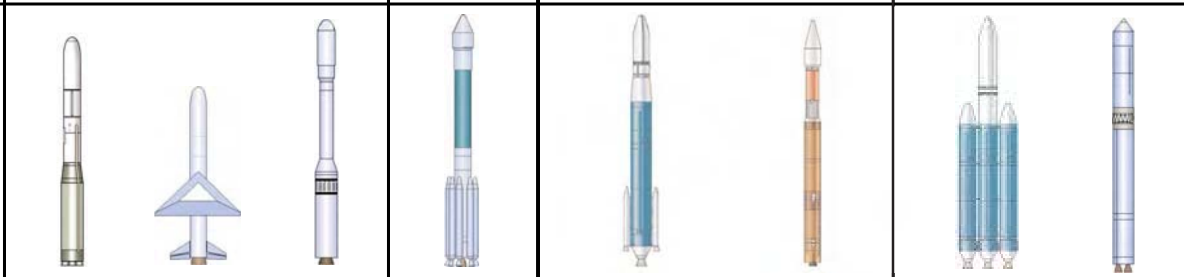
Delta II – United Launch Alliance

The Delta II launch vehicle, in service since 1989, traces its heritage to the Thor missile program of the 1950s. Since December 2006 the Delta II has been produced by ULA, and is marketed commercially by Boeing Launch Services (BLS). The Delta II has the capability to launch payloads of 900 to 2,170 kilograms (1,980 to 4,790 pounds) to GTO, and 2,700 to 6,100 kilograms (5,960 to 13,440 pounds) to low Earth orbit (LEO), and can launch from either CCAFS or VAFB.

Delta II

There were eight Delta II launches in 2006, including commercial launches of the Cosmo-Skymed 1, WorldView-1, and Cosmo-Skymed 2 satellites in June, September, and December, respectively, from VAFB. As many as nine Delta II launches, including three commercial missions, are planned for 2008.

Table 1: Currently Available Expendable Launch Vehicles

	Small			Medium	Intermediate		Heavy	
								
Vehicle	Minotaur	Pegasus XL	Taurus XL	Delta II	Delta IV	Atlas V	Delta IV Heavy	Zenit-3SL
Company	Orbital Sciences	Orbital Sciences	Orbital Sciences	ULA	ULA	ULA	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 IV M) 13,360 kg (29,440 lb) (Delta IV M+ (5,4))	12,500 kg (27,560 lb) (Atlas V 402) 20,520 kg (45,240 lb) (Atlas V 552)	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 IV M) 11,300 kg (24,920 lb) (Delta IV M+ (5,4))	7,095 kg (15,640 lb) (Atlas V 402) 14,095 kg (31,075 lb) (Atlas V 552)	22,560 kg (49,740 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 IV M) 7,020 kg (15,470 lb) (Delta IV M+ (5,4))	4,950 kg (10,910 lb) (Atlas V 401) 8,670 kg (19,120 lb) (Atlas V 551)	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, VAFB	CCAFS, VAFB	Pacific Ocean

Delta IV – United Launch Alliance

The Delta IV is one of two launch vehicles developed for the EELV program in the 1990s. The Delta IV was designed by Boeing, and since December 2006 has been produced by ULA. Originally developed for both commercial and government applications, the Delta IV is currently marketed only to U.S. government customers.

The Delta IV is available in five versions, four Medium versions, with varying payload fairing sizes and number of strap-on boosters, and one

Delta IV Heavy

Heavy version, which uses three common booster core stages instead of one. 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). The Delta IV operates from CCAFS and VAFB.

The Delta IV has flown seven times since its introduction in late 2002. One Delta IV Heavy launch, of the DSP 23 satellite, took place in 2007. Up to four Delta IV launches, including one FAA-licensed mission, are planned for 2008.

Minotaur I – Orbital Sciences Corporation

Minotaur I

Under the U.S. Air Force's Orbital/Suborbital Program (OSP), Orbital Sciences Corporation has developed the Minotaur family of launch vehicles, starting with the Minotaur I, to launch small government payloads. The Minotaur I 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, while the upper two stages are Orion 50 XL and Orion 38 motors from the Pegasus XL.

The Minotaur I entered service in 2000 and has performed seven launches to date, including the launch of the NFIRE satellite in 2007 from the Mid-Atlantic Regional Spaceport (MARS) in Virginia. A Minotaur I is scheduled to launch the TacSat-3 satellite in 2008, also from MARS. The Minotaur I has previously performed launches from VAFB, and can operate from CCAFS and Kodiak Launch Complex, Alaska.

Pegasus XL – Orbital Sciences Corporation

The Pegasus XL is an air-launched booster designed for small payloads, primarily to low Earth and sun-synchronous orbits. Introduced in 1994, the Pegasus XL is a derivative of the original Pegasus rocket, with stretched first and second stages. (The original Pegasus, first launched in 1990, was retired in 2000.) The Pegasus XL, with three solid-propellant stages and an optional hydrazine monopropellant upper stage, is deployed from an Orbital Sciences L-1011 aircraft named "Stargazer." The air-launched nature of the Pegasus XL allows missions to be staged from a variety of sites, including Edwards Air Force Base (EAFB) and VAFB in

Pegasus XL

California; CCAFS and KSC in Florida; NASA Wallops Flight Facility (WFF) in Virginia; Kwajalein Missile Range, Marshall Islands; and Gando Air Force Base (GAFB), Canary Islands.

The Pegasus XL performed one launch in 2007, launching NASA's Aeronomy of Ice in the Mesosphere (AIM) mission out of VAFB. Two Pegasus XL missions are scheduled for 2008.

Taurus – Orbital Sciences Corporation

Taurus

The Taurus 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). The goal was to develop a standard launch vehicle that could set up quickly in new locations and launch small satellites that are too large for the Pegasus XL. The Taurus uses the three stages of a Pegasus (without wings or stabilizers) stacked atop a Castor 120 solid rocket motor. The Castor 120 serves as the first stage of the Taurus. The Taurus is available in standard and XL versions. The Taurus successfully completed six of seven launch attempts since entering service in 1994. No Taurus launches took place in 2007, but two are scheduled for 2008.

Zenit-3SL – Sea Launch Company, LLC

The Zenit-3SL is a Ukrainian-Russian launch vehicle operated by Sea Launch Company, LLC, a multinational joint venture featuring four partners.

Ukrainian sister companies SDO Yuzhnoye and PO Yuzhmash provide the first two stages, 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. The Norwegian shipbuilding company, Aker, designed and built the two Sea Launch vessels and contracts marine operations. 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 approximately 6.5 kilometers (about 4 miles) uprange from the platform during launch operations. Sea Launch conducts commercial launches with a license from FAA. Under current U.S. space transportation policy, the mostly foreign-manufactured Zenit-3SL vehicle is not available for launch of U.S. government payloads.

Zenit 3SL

The first Zenit-3SL launch of 2007 ended in failure on January 30 when the vehicle lost thrust moments after ignition of the first stage engine, destroying the vehicle and its payload, the NSS-8 satellite. An investigation concluded that metallic debris became lodged in the liquid oxygen turbopump in the engine, initiating combustion in the chamber, and leading to the destruction of the engine and launch vehicle.[13] The Sea Launch team has since taken measures to prevent the problem from recurring, and also repaired and recertified the Odyssey, which suffered minor damage, including the loss of its flame deflector. The Zenit-3SL is scheduled to return to flight with the launch of the Thuraya-3 satellite in January 2008, part of a full manifest of up to five launches scheduled for the year.[14]

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 LEO payload sector of the launch market, and reducing launch costs is a key goal.

ALV – Alliant Techsystems

Vehicle: ATK Launch Vehicle
Developer: Alliant Techsystems
First Launch: 2008 (suborbital); 2010 (orbital)
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

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 existing rocket stages 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 2008 from MARS in Virginia. ATK plans to offer a larger orbital version of the ALV for government and commercial customers seeking responsive launches of small satellites in 2010 and beyond.[15]

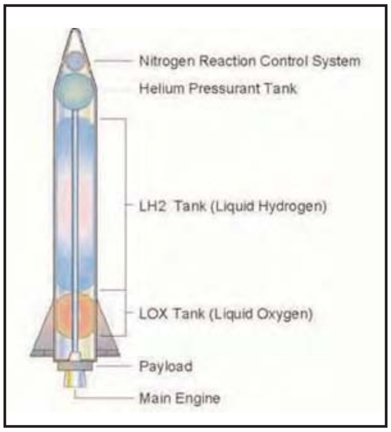
ALV

Aquarius – Space Systems/Loral

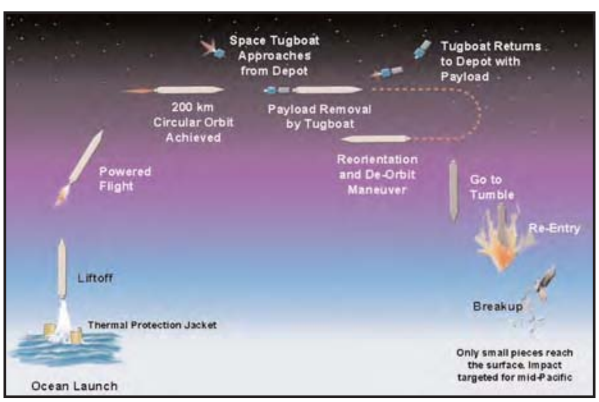
Space Systems/Loral of Palo Alto, California, has proposed Aquarius, a low-cost launch vehicle designed to carry small, inexpensive payloads into LEO. This vehicle's mission will consist primarily of launching inexpensive-to-replace bulk products, such as water, fuel, and other consumables, into space. As currently designed, Aquarius will be a single-stage vehicle 43 meters (141 feet) high and 4

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

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 200-kilometer (125-mile) orbits at any desired inclination. It can do this because 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.



Aquarius



Aquarius mission profile

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 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.[16]

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: MARS
Markets Served: Small satellite launch

E'Prime Aerospace of Falls Church, Virginia, 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

Eaglet and Eagle

with the U.S. Air Force to use Peacekeeper technology for commercial launch vehicles. In August 2007 E'Prime Aerospace announced that it had selected MARS as its primary launch site and will develop infrastructure there to support its vehicles. The company also started the process of obtaining a launch license from FAA, and in November 2007 was notified that the application had cleared an interagency policy review, removing any government obstacles to its use of its Peacekeeper-derived motors.[17]

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

Lockheed Martin Michoud Operations of New Orleans, Louisiana, was awarded one of four DARPA Force Application and Launch from CONUS (FALCON) contracts in September 2004. This $11.7 million contract tasks Lockheed Martin 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.[18]

FALCON SLV

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

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.

Prospector 8A

On September 15, 2007, the GSC/CSULB team launched the Prospector 8A (P-8A) rocket from the Mojave Desert in California. The rocket featured the first flight of a new 20,000-newton (4,500-pounds-force) engine designed for future prototypes of the NLV. The loss of the P-8A's tail fins four seconds into the flight caused the vehicle to tumble out of control.[19] GSC is incorporating design lessons from that flight into its next vehicle, the Prospector 9 (P-9), currently under development under a Phase 2 Small Business Innovation Research from the USAF. GSC and its research partner, CSULB, plan five launches in the next year of the P-9 and two other vehicles, Prospectors 10 and 12.[20]

Sprite SLV – Microcosm, Inc.

Vehicle: Eagle SLV

Developer: Microcosm, Inc.

First Launch: TBD

Number of Stages: 3

Payload Performance: 481 kg (1,060 lb) to LEO

Launch Site: VAFB, WFF, CCAFS

Markets Served: Small satellite launch, responsive space operations

Microcosm, Incorporated, of Hawthorne, California, has been developing the Scorpius family of ELVs. Several versions are under consideration, and two prototype 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 five Scorpius variants. Each Scorpius variant is based on a scalable modular design featuring simple, LOX/Jet-A, pressure-fed engines without turbopumps and low-cost avionics equipped with GPS/INS (global positioning system/inertial navigation system). The thick propellant tanks provide added durability during flight and ground handling. The orbital variants have three stages.

Sprite SLV

The suborbital variant, the SR-M, which is essentially one of seven nearly identical “pods” of the Sprite orbital vehicle, has been built and has a maximum payload of 1,089 kilograms (2,400 pounds). Four orbital variants are planned. The Sprite Small Launch Vehicle (SLV) is projected to loft up to 481 kilograms (1,060 pounds) to LEO. Microcosm's light-, medium-, and heavy-lift Scorpius variants will deploy payloads to LEO and to GTO with an upper stage. The Liberty Light-Lift vehicle would loft up to 1,924 kilograms (4,240 pounds) to LEO and up to 757 kilograms (1,670 pounds) to GTO. The Exodus Medium-Lift vehicle would deploy up to 8,938 kilograms (19,700 pounds) to LEO and up to 3,518 kilograms (7,760 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 work on the project under corporate funding, which continues at present, while looking for additional funding to restart development of the Sprite SLV.[21]

Minotaur IV and V – Orbital Sciences Corporation

Vehicle: Minotaur IV and V

Developer: Orbital Sciences Corporation

First Launch: 2008 (Minotaur IV); TBD (Minotaur V)

Number of Stages: 4 (Minotaur IV); 5 (Minotaur V)

Payload Performance: 1,750 kg (3,860 lb) to LEO (Minotaur IV); 675 kg (1,495 lb) to GTO (Minotaur V)

Launch Site: MARS, VAFB

Markets Served: Small satellite launch and responsive space operations for U.S. government-sponsored payloads

Under a contract with the USAF Space and Missile Systems Center, Orbital Sciences Corporation is currently developing the Minotaur IV launch vehicle for U.S. government payloads. The Minotaur IV is derived from the Peacekeeper ICBM, using three Peacekeeper solid-propellant stages and an Orion 38 motor for the fourth stage. The Minotaur IV uses a standard 234-centimeter (92-inch) payload fairing also used on Orbital’s Taurus rocket. The first Minotaur IV launch is scheduled for late 2008, when it will launch the Space-Based Surveillance System (SBSS) satellite for the USAF.

Minotaur IV

Orbital is also developing a derivative of the Minotaur IV, called the Minotaur V, for payloads launched to orbits beyond LEO. The Minotaur V features the same three Peacekeeper-based lower stages, but uses a Star 48 fourth stage and Star 37 fifth stage, allowing it to put 678 kilograms (1,495 pounds) into GTO and 440 kilograms (970 pounds) on a translunar injection trajectory. The Minotaur V shares many of the same subsystems as the Minotaur IV, requiring only an additional $10 million in non-recurring engineering expenses to complete its development.[22]

QuickReach – AirLaunch LLC

Vehicle:	QuickReach
Developer:	AirLaunch LLC
First Launch:	2010
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

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, with a response time of less than 24 hours.

QuickReach

In July 2006, AirLaunch LLC conducted the safe release of a full-scale dummy rocket from an Air Force C-17 cargo airplane. The demonstration was a follow-on to two prior drop tests. AirLaunch LLC did not perform further drop tests in 2007.

During 2007 AirLaunch completed work on Phase 2B of the DARPA/USAF Falcon small launch vehicle program, including numerous tests of its liquid oxygen/propane vapor pressurization (VaPak) system. AirLaunch achieved the longest-ever burn of a VaPak engine system with a 191-second engine firing on a test stand at Mojave Air and Space Port, California, in April 2007. In June 2007 AirLaunch received a $7.6-million contract for Phase 2C of the Falcon program. The contract covers continued development and testing of the VaPak system.[23] Phase 2 is anticipated to conclude with the test launch of a QuickReach rocket in approximately 2010.[24]

Taurus 2 – Orbital Sciences Corporation

Vehicle:	Taurus 2
Developer:	Orbital Sciences Corporation
First Launch:	2010
Number of Stages:	2
Payload Performance:	6,000 kg (13,225 lb) to LEO
Launch Site:	TBD
Markets Served:	Medium-class payloads for government and commercial customers

In 2007, Orbital Sciences Corporation announced that it had begun a study of a new launch vehicle, the Taurus 2, designed to serve medium-class payloads for U.S. government and commercial customers. The Taurus 2's first stage would be powered by a pair of Aerojet AJ26-58 engines, a version of the NK-33 engine developed for the Soviet Union's N-1 lunar rocket in the 1960s; Orbital has not disclosed any information about the vehicle's upper stages. The Taurus 2 would be able to place 6,000 kilograms (13,225 pounds) into LEO and 3,700 kilograms (8,150 pounds) into sun-synchronous orbit. Enhanced versions of the Taurus 2 could be used to launch payloads of up to 3,000 kilograms (6,600 pounds) into GEO. Orbital plans to make a decision on developing the Taurus 2 in 2008, with the first launch projected to occur in mid-2010.[25]

Z-1 – Zig Aerospace, LLC

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

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

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.[26]

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

Vehicle: Zenit-3SLB
Developer: Space International Services
First Launch: 2008
Number of Stages: 3
Payload Performance: 3,600 kg (7,940 lb) to GTO
Launch Site: Baikonur
Markets Served: Commercial GEO satellite launch

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 lifting heavy payloads, or groups of payloads, to LEO.

Zenit-3SLB

Payloads and vehicles will be processed and launched from existing Zenit facilities at the Baikonur launch site. The first Land Launch mission is scheduled for 2008. To date, Sea Launch, which manages marketing and sales for this new offering (in addition to its sea-based missions), has received seven commercial orders for the Land Launch service.[27]

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 I) and the Cargo Launch Vehicle (renamed the Ares V). 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 I

Vehicle: Ares I
Developer: NASA
First Launch: 2009 (suborbital); 2014 (orbital)
Number of Stages: 2
Payload Performance: 22,700 kg (50,000 lb) to LEO
Launch Site: KSC
Markets Served: Crew launches for exploration and ISS missions

The Ares I 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 I 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; it uses LOX and liquid hydrogen propellants. The Orion spacecraft, along with an escape rocket, will be mounted on top of the second stage.

Ares I

Development of the Ares I is currently in progress. In July 2007 NASA awarded Pratt & Whitney Rocketdyne a $1.2-billion contract for the J-2X engine.[28] In August 2007, NASA selected Boeing to build the upper stage of the Ares I.[29] NASA also awarded Boeing a contract in December 2007 for the instrument unit avionics for the Ares I, the last major component of the launch vehicle to be assigned to a contractor.[30] The first test flight of the Ares I, designated Ares I-X and planned for 2009, will be a suborbital launch with an inert second stage. The Ares I is scheduled to enter service no later than 2014.

Ares V

Vehicle: Ares V
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

The Ares V 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 V uses two, five-segment RSRMs similar to those developed for the Ares I 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 now used on the Delta IV family of vehicles. Under the current exploration architecture, an Ares V 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 I. The combined vehicle would then leave Earth orbit for the Moon. Detailed development of the Ares V is not expected to begin until the end of the decade.

Ares V

Sounding Rockets

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

Black Brant – Bristol Aerospace Limited

Over 1,000 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 Nikha motors used on some Black Brant versions are manufactured in Canada by Bristol Aerospace Limited (a Magellan Aerospace Company). Terrier, 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.

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).[31]

Black Brant

Oriole – DTI Associates

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 was scheduled for delivery in late 2007.


Oriole

Terrier-Orion – DTI Associates

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 12 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 third 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.


Terrier Orion

Hybrid Sounding Rocket Program – Lockheed Martin-Michoud

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.

Hybrid Test Rocket – Lockheed Martin-Michoud and Nammo AS

Lockheed Martin-Michoud partnered with a Norwegian company, Nammo Raufoss AS, to build the Hybrid Test Rocket (HTR), a single-stage hybrid-propulsion sounding rocket. Lockheed Martin-Michoud provided the design, engineering schematics, and vehicle assembly plan, with the actual production of the rocket performed by Nammo AS. The HTR uses liquid oxygen and rubberized HTPB as fuel, has a 31,000-newton (7,000-pound-force) thrust, and a burn time of 30 to 35 seconds. Its peak altitude is designed 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 in order to gain approval for the 17-month design and handoff project. On May 3, 2007, the HTR flew successfully from the Andøya Rocket Range in Norway. Nammo AS considered the HTR a test vehicle only, giving the company expertise in the development and operation of hybrid propulsion systems.[32]

SpaceLoft XL – UP Aerospace, Inc.

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.

Spaceloft XL

The first successful SpaceLoft XL launch took place on April 28, 2007, from Spaceport America in New Mexico.[33] The rocket reached a peak altitude of 117.5 kilometers (72.7 miles), landing in a mountainous region of the approved landing zone at White Sands Missile Range, New Mexico. The rocket carried over 50 student experiments as well as commercial payloads from several companies.[34]

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 efforts.

Commercial RLV Development Efforts

Tiger & Cardinal – Acuity Technologies

Vehicle: Tiger & Cardinal

Developer: Acuity Technologies

First Launch: TBD

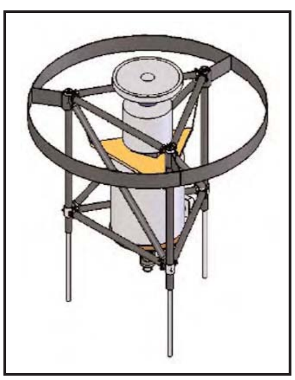
Number of Stages: 1

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

Launch Site: TBD

Targeted Market: Lunar Lander Challenge competition

Acuity Technologies of Menlo Park, California, has been developing the Tiger and Cardinal vehicles to compete in the two levels of the Northrop Grumman Lunar Lander Challenge competition. Both vehicles are vertical takeoff and vertical landing designs powered by isopropyl alcohol and 59-percent concentration hydrogen peroxide. The vehicles are designed to maneuver autonomously and can also be controlled from the ground via a standard remote control aircraft radio link. Neither vehicle was ready to enter the 2007 competition but may participate in future competitions.[35]



Tiger and Cardinal

MOD – Armadillo Aerospace

Vehicle: MOD

Developer: Armadillo Aerospace

First Launch: 2007

Number of Stages: 1

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

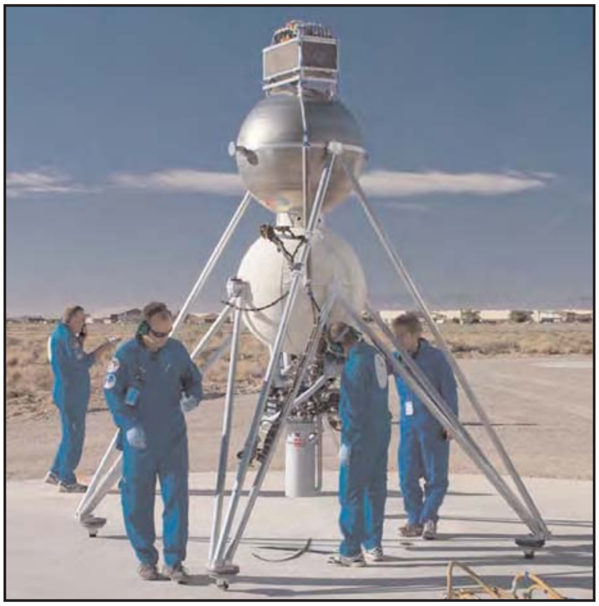
Launch Site: Oklahoma Spaceport, Holloman Air Force Base

Targeted Market: Lunar Lander Challenge competition, future suborbital and orbital launch applications

Armadillo Aerospace, a former competitor for the Ansari X Prize, is developing a family of vehicles designed for suborbital and, eventually, orbital flight opportunities. In 2007, Armadillo developed the MOD-1 vehicle, a variant of the Quad vehicle Armadillo built in 2006 to compete for the Northrop Grumman Lunar Lander Challenge. The MOD-1 consists of a single pair of propellant tanks (the Quad design featured two pairs of tanks) above a LOX/ethanol engine, with payload and electronic boxes on top of the tanks. The vertical-takeoff, vertical-landing vehicle is supported by four large landing legs.

Armadillo received an experimental permit for MOD-1 in 2007 and performed flights of the vehicle under that permit during the year. On October 20, MOD-1 performed a low-level flight test at the Oklahoma Spaceport to demonstrate it was capable of performing the flight profile needed to win Level One of the Lunar Lander Challenge. MOD-1 then made four flights at Holloman Air Force Base, New Mexico, during the 2007 X PRIZE Cup in an effort to win the competition. The vehicle successfully flew the first leg of the Level One challenge on the afternoon of October 27, but during the return leg suffered a "hard start" of its engine; the engine shut down with about seven seconds remaining in the flight as it hovered over the landing pad. On the morning of October 28, Armadillo made another attempt to win the prize with the MOD-1, flying the initial leg of the flight profile successfully. On the return trip, however, the engine suffered another hard start and made a powered abort several seconds after ignition. A final attempt to win the prize on the afternoon of

October 28 failed when the engine suffered another hard start, blowing off the engine chamber and starting a fire before the vehicle could lift off.[36]



MOD-1 on the pad at the 2007 X PRIZE Cup

After diagnosing and resolving these engine problems, Armadillo plans to continue development of the MOD-1, using it as the basis for a series of increasingly-powerful modular vehicles. Future plans call for testing vehicles that use two or more MOD-1 vehicles in combination. A “six-pack” variant using six modules would be capable of carrying a payload on a suborbital trajectory to 100 kilometers (62 miles) altitude and could begin flight tests in 2008. Even larger vehicles, using dozens of identical modules, could be used to launch small payloads into orbit.[37]

BSC Spaceship – Benson Space Company

Vehicle: BSC Spaceship
Developer: Benson Space Company
First Launch: 2009
Number of Stages: 1
Payload Performance: 6 people to at least 105 km (65 mi)
Launch Site: TBD
Targeted Market: Suborbital space tourism

Benson Space Company (BSC), of Poway, California, was established by former SpaceDev CEO Jim Benson in September 2006 to develop and operate vehicles to serve the suborbital space tourism market. BSC originally planned to operate a suborbital version of the Dream Chaser spacecraft proposed by SpaceDev. However, in May 2007, BSC unveiled a new vehicle concept, the BSC Spaceship. The vehicle is an amalgam of several previous NASA and USAF aircraft and rocketplanes, including the X-2, X-15, and T-38. The BSC Spaceship will take off vertically using hybrid motors; after reaching a peak altitude of at least 105 kilometers (65 miles), the vehicle will perform a low-g “carefree” reentry—using an approach called variable ballistic coefficient slowing—and land on a runway. BSC believes the BSC Spaceship will be faster and less expensive to construct than previous designs, allowing it to enter commercial service as early as 2009.[38]

BSC Spaceship

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 Site: Culberson County, Texas
Targeted Market: Suborbital space tourism

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.

Blue Origin's Goddard prototype vehicle

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.

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, named Goddard, is powered by an HTP monopropellant engine and is intended to 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 flight took place on November 13, 2006, followed by flights on March 22 and April 19, 2007.

Sea Star – Interorbital Systems

Vehicle: Sea Star	
Developer: Interorbital Systems	
First Launch: 2nd quarter 2008	
Number of Stages: 2.5	
Payload Performance: 26 kg (58 lb) to LEO	
Launch Site: Pacific Ocean west of Long Beach, California	
Targeted Market: Microsatellite launches	

Interorbital Systems of Mojave, California, is developing the Sea Star for microsatellite payloads weighing up to 26 kilograms (58 pounds) and as a testbed for its larger Neptune orbital launch vehicle. These vehicles are constructed for design simplicity. The vehicle consists of a booster module with four rocket engines, a sustainer module with four additional engines as well as propellant tanks and guidance control systems, and a satellite module that contains the payload and one small rocket engine. All the engines use a combination of storable hypergolic propellants: white fuming nitric acid (WFNA) 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. Initial test launches of the vehicle are planned for the second quarter of 2008.[39]

Sea Star

Neptune – Interorbital Systems

Vehicle: Neptune	
Developer: Interorbital Systems	
First Launch: TBD	
Number of Stages: 1.5	
Payload Performance: 3,175 kg (7,000 lb) to LEO	
Launch Site: Pacific Ocean west of Long Beach, California	
Targeted Market: Orbital space tourism	

Neptune is a scaled-up version of Interorbital Systems' Sea Star rocket and is intended to carry passengers into orbit. The Neptune uses a design similar to the Sea Star vehicle, with a booster module that has four high-thrust rocket engines and a sustainer module with four medium-thrust engines. The vehicle can place 3,175 kilograms (7,000 pounds) into a 51-degree, 400-kilometer (250-mile) orbit.

A unique aspect of the Neptune is that the main rocket structure, once in orbit, can act as a small space station. A conical crew module attached to the top of the rocket, carrying up to five people, would undock, turn 180 degrees, and dock nose-first with the orbital station module. The 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.[40]

Neptune

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 Site: Mojave Air and Space Port
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.

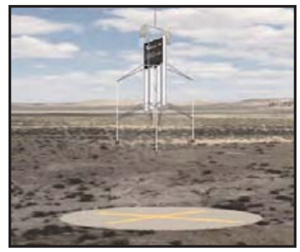
As part of the development of the XA 1.0, Masten is building several prototype vehicles. The first, the XA 0.1, began tethered flight tests in 2007; the vehicle was destroyed during one such test flight in December 2007.[41] A larger prototype, the XA 0.2, is currently under development, with plans to fly the vehicle in the 2008 Lunar Lander Challenge.

XA 1.0

Crusader LL – Micro-Space

Vehicle: Crusader LL
Developer: Micro-Space
First Launch: TBD
Number of Stages: 1
Payload Performance: 25 kg (55 lb) to 50 m (165 ft)
Launch Site: TBD
Targeted Market: Lunar Lander Challenge competition

Micro-Space of Denver, Colorado, is developing the Crusader LL vehicle to compete the Northrop Grumman Lunar Lander Challenge competition. The vehicle is a vertical takeoff and vertical landing design powered by a set of engines using methyl alcohol and hydrogen peroxide. The modular design allows for scaled-up vehicle designs capable of suborbital spaceflight and actual lunar lander vehicles. While Micro-Space was not able to compete in the 2007 competition, the company is preparing to participate in future events.[42]



Crusader LL

Crusader HTS – Micro-Space

Vehicle: Crusader HTS
Developer: Micro-Space
First Launch: TBD
Number of Stages: 1
Payload Performance: 120 kg (265 lb) to 50 km (31 mi)
Launch Site: TBD
Targeted Market: Space diving, human lunar landing, Google Lunar X PRIZE

Micro-Space of Denver, Colorado, is developing the Crusader HTS vehicle to compete the Google Lunar X PRIZE competition as well as for human transportation uses. This vehicle is a vertical takeoff and vertical landing design powered by a set of engines using methyl alcohol and hydrogen peroxide. This high mass ratio system, coupled with the higher performance of rocket motors in vacuum, will permit the vehicle not only to compete in Level 2 of the Northrop Grumman Lunar Lander Challenge but also to actually land a spacesuit-clad astronaut on the Moon. This design positions a standing human between two clusters of fuel tanks. A compact rover will be substituted for the Google Lunar X PRIZE competition. Parachute-fitted users can easily dive from the launch vehicle at a wide range of altitudes above the Earth. The lunar applications assume commercial launch services to lift the landers, payload, and transstage to orbit. MicroSpace has also developed a range of short and long term life support systems for lightweight human spaceflight.[43]

Volkon – Paragon Labs

Vehicle: Volkon
Developer: Paragon Labs
First Launch: TBD
Number of Stages: 1
Payload Performance: 25 kg (55 lb) to 50 m (165 ft)
Launch Site: TBD
Targeted Market: Lunar Lander Challenge competition

Paragon Labs, of Denver, Colorado, is building the Volkon vehicle to compete in the Northrop Grumman Lunar Lander Challenge. The vehicle is a vertical takeoff, vertical landing vehicle powered by an engine using liquid oxygen and E85 ethanol, the first known use of E85 in a bipropellant rocket engine. Volkon was not ready to compete in the 2007 competition, but Paragon Labs plans to continue development of the vehicle in order to participate in future competitions.[44]

Volkon

Silver Dart – PlanetSpace

Vehicle: Silver Dart
Developer: PlanetSpace
First Launch: TBD
Number of Stages: 3
Payload Performance: TBD
Launch Site: Cape Breton Space Port, Nova Scotia, Canada
Targeted Market: Passenger and cargo missions to LEO

PlanetSpace, headquartered in Chicago, Illinois, is developing the Silver Dart reusable spacecraft for missions to LEO. The Silver Dart is based on the FDL-7 hypersonic glider design originally proposed by the U.S. Air Force Flight Dynamics Laboratory in the late 1950s. The vehicle design features an all metal thermal protection system to enable flight in all weather conditions. The Silver Dart has a glide range of 40,000 kilometers (25,000 miles), or one orbit of the Earth, and a cross range of over 6,400 kilometers (4,000 miles), allowing the vehicle to leave LEO at any time and still land in the continental U.S. PlanetSpace proposed to launch the Silver Dart with an expendable rocket called Nova, also under development, from a proposed spaceport in Cape Breton, Nova Scotia.[45]

Silver Dart

Rocketplane XP – Rocketplane Global

Vehicle: Rocketplane XP
Developer: Rocketplane Global
First Launch: 2010
Number of Stages: 1
Payload Performance: 6 people to 100 km (62 mi)
Launch Sites: Oklahoma Spaceport
Targeted Market: Suborbital space tourism, microgravity research

Rocketplane Global, a subsidiary of Rocketplane Inc. of Oklahoma City, Oklahoma, is developing the Rocketplane XP suborbital RLV. The vehicle will take off under jet power. At an altitude of at least 12,200 meters (40,000 feet), it will ignite a single AR-36 rocket LOX and kerosene rocket engine provided by Polaris Propulsion for a

70-second burn. The Rocketplane XP will fly to an altitude of at least 100 kilometers (62 miles) before reentering and landing, either under jet power or unpowered, at the same site as takeoff.

Rocketplane XP

In October 2007, Rocketplane Global unveiled a new design for the Rocketplane XP. The previous design, based on a highly-modified Learjet fuselage, was replaced with a larger cabin capable of carrying one pilot and five passengers. The jet engines were upgraded to the more powerful J-85 version. The V-tail of the previous design has been replaced with a T-tail, and the landing gear with a model based on the gear used for the F-5 aircraft. Rocketplane Global estimates that over 200,000 person-hours went into developing the new design. The company anticipates beginning flight tests in 2010, contingent on raising sufficient capital to fund vehicle development.[46]

K-1 – Rocketplane Kistler

Vehicle: K-1

Developer: Rocketplane Kistler

First Launch: TBD

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

Rocketplane Kistler (RpK), a subsidiary of Rocketplane Inc. of Oklahoma City, Oklahoma, is 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 first stage of the K-1, called the Launch Assist Platform (LAP), is powered by three LOX/kerosene GenCorp Aerojet AJ26-58/-59 engines, capable of generating 4.54 million newtons (1.02 million pounds-force) of thrust. 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, using parachutes and air bags. The second stage, called the 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. Initial flights of the K-1 are planned to take place from Spaceport Woomera in South Australia, with later flights staged from a U.S. site to be determined.

K-1

RpK was formed in early 2006 with the merger of Rocketplane Ltd. with Kistler Aerospace Corporation, which had been developing the K-1 concept since the 1990s but had suspended work because of financial problems. In August 2006, RpK was one of two companies to receive a funded COTS award from NASA to help develop the K-1 to service the ISS. The company achieved several milestones outlined in the Space Act agreement with NASA for the COTS program through early 2007, including a system requirement review for the K-1.[47] However, the company failed to achieve a financial milestone of the COTS agreement requiring it to raise several hundred million dollars of private capital to fully fund the development of the K-1. In October 2007, NASA announced it had terminated the COTS agreement with RpK after awarding the company only $32.1 million of the original $207 million.[48]

SpaceShipTwo –
Scaled Composites, LLC/The Spaceship Company/Virgin Galactic

Vehicle: SpaceShipTwo

Developer: Scaled Composites

First Launch: 2010

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, LLC a subsidiary of the Virgin Group of Companies, announced the formation of a joint venture, called The Spaceship Company (TSC), LLC, in July 2005. The purpose of TSC is to oversee development and production of SpaceShipTwo, a commercial suborbital spacecraft based on technology developed for SpaceShipOne. TSC will produce the first five SpaceShipTwo vehicles for Virgin Galactic, which plans to put them into commercial service once test flights are completed, offering suborbital space flights for private individuals, science research, and payload. 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.

During 2007, Virgin Galactic's first 100 customers were invited to undertake g-force training at the NASTAR training center outside Philadelphia. The resulting unique dataset is now being used by the company as it develops its policies for future customer training and safety.

SpaceShipTwo

In January 2008, Virgin Galactic and Scaled Composites unveiled the designs for WhiteKnightTwo and SpaceShipTwo before the start of the test flight program for both vehicles scheduled for 2008.[49]

Dream Chaser – SpaceDev

Vehicle: Dream Chaser

Developer: SpaceDev

First Launch: 4th quarter 2009 (suborbital), 2nd quarter 2011 (orbital)

Number of Stages: 2 (suborbital), 3 (orbital)

Payload Performance: 6-9 people

Launch Site: Spaceport America (suborbital), CCAFS (orbital)

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

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 has been expanded from the original HL-20 by 10% to an overall length of 9.6 meters (31.5 feet) and wingspan of 8 meters (26.2 feet). The Dream Chaser is capable of transporting 6-9 passengers, compared to the original HL-20's capacity of 6-10. For suborbital flights, the vehicle will launch vertically, using hybrid engines. On orbital flights, the vehicle will launch on top of existing launch vehicles. In both scenarios, the vehicle will glide to a runway landing.

Dream Chaser

The Dream Chaser concept was one of the finalists in the original round of NASA's COTS competition, and was resubmitted as a bid for the COTS-2 competition. In June 2007, NASA and SpaceDev signed an unfunded Space Act agreement (SAA) where NASA will provide technical support and other information to SpaceDev to aid in the ongoing development of Dream Chaser.[50] SpaceDev has completed two technical milestones to date under the unfunded SAA. In addition, SpaceDev signed a memorandum of understanding with ULA in April 2007 to study the use of the Atlas 5 to launch Dream Chaser on orbital missions.[51] SpaceDev is also working with ATK to study the integration of the Dream Chaser on an Ares 1-derived launch vehicle.

Skyhopper – Space Access, LLC

Vehicle:	Skyhopper
Developer:	Space Access, LLC
First Launch:	2011
Number of Stages:	1
Payload Performance:	TBD
Launch Site:	Near Corpus Christi, Texas
Targeted Market:	Suborbital space tourism

In December 2007, Space Access, LLC, of Huntertown, Indiana, announced its plans to develop a suborbital RLV called Skyhopper. The vehicle would take off and land on a conventional runway, and use ejector ramjet engines with liquid hydrogen fuel, as opposed to conventional rocket engines. Space Access anticipates Skyhopper will reach speeds of up to Mach 7 and altitudes in excess of 100 kilometers (62 miles). The company plans on building up to eight Skyhopper vehicles and operate up to 15 flights per day. Suborbital flight operations are scheduled to begin in 2011, initially from a facility to be developed south of Corpus Christi, Texas. Orbital flights, using a variant of Skyhopper, are projected to begin as soon as 2014.[52]

Skyhopper

Falcon 1 – Space Exploration Technologies Corporation

Vehicle:	Falcon 1
Developer:	Space Exploration Technologies Corporation
First Launch:	2006
Number of Stages:	2
Payload Performance:	475 kg (1,050 lb) to LEO
Launch Site:	Kwajalein Atoll, VAFB
Targeted Market:	Small satellite launch

SpaceX of Hawthorne, California, has developed the partially reusable Falcon 1 launch vehicle, that can place up to 475 kilograms (1,050 pounds) into LEO for about $7 million. The first stage of this vehicle is designed to parachute into the ocean. It can then be recovered, 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. The Falcon 1e, an enhanced version of the Falcon 1 with a stretched first stage and larger payload fairing, is slated to enter service in 2009; it will be able to place up to 725 kilograms (1,600 pounds) into LEO for $8.5 million.[53]

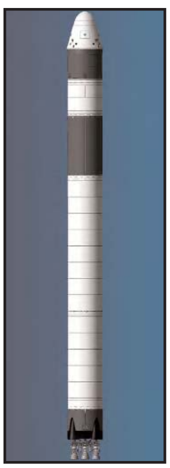
Falcon 1

The second Falcon 1 launch, designated Demo Flight 2, took place on March 20, 2007, from Omelek Island in the Kwajalein Atoll in the Pacific Ocean. The vehicle failed to reach orbit because of an upper stage control anomaly that coupled with slosh in the stage's LOX tank. This caused a rolling motion that centrifuged the propellants away from the tank outlets and caused the engine to shut down prematurely. SpaceX has taken several steps to resolve the problem, including installing slosh baffles in the second stage LOX tank.[54] Falcon 1 will return to flight in early 2008, carrying a number of small payloads, to be followed by the first Falcon 1 commercial launch, of the Malaysian remote sensing spacecraft Razaksat.

Falcon 9 – Space Exploration Technologies Corporation

Vehicle: Falcon 9
Developer: Space Exploration Technologies Corporation
First Launch: 2008
Number of Stages: 2
Payload Performance: Up to 27,500 kg (60,600 lb) to LEO, 12,000 kg (26,500 lb) to GTO
Launch Site: Kwajalein Atoll, VAFB
Targeted Market: Launch of medium and large satellites, ISS crew and cargo resupply

The Falcon 9 vehicle is a two-stage RLV designed to launch large spacecraft as well as cargo and crew resupply missions to the ISS. The first stage uses nine Merlin 1C engines, the same engine as used on the first stage of the Falcon 1. The second stage, a shortened version of the first stage, uses a single Merlin engine. Both stages are designed to be recovered and reused. The Falcon 9 can place up to 9,900 kilograms (21,820 pounds) into LEO and 4,900 kilograms (10,800 pounds) into GTO. A variant, the Falcon 9 Heavy, uses two additional first stages as strap-on boosters, like the Delta IV Heavy, and can place up to 27,500 kilograms (60,600 pounds) into LEO and 12,000 kilograms (26,500 pounds) into GTO.[55] Launch costs range from $35 million for the medium version to $90 million for the heavy version, in 2007 dollars.[56]


Falcon 9

The first Falcon 9 launch, a demonstration mission, is scheduled for the fourth quarter of 2008. SpaceX will perform three launches in 2008 and 2009 as part of its COTS agreement with NASA; other Falcon 9 customers include MacDonald, Dettwiler and Associates Ltd. of Canada, Bigelow Aerospace, and Avanti Communications, which signed the first contract for the Falcon 9 launch of a commercial communications satellite in September 2007.[57] In November 2007, SpaceX broke ground on new launch facilities for the Falcon 9 at Space Launch Complex 40, a former Titan 4 launch pad at CCAFS. The facility will be ready to support the first Falcon 9 launch in late 2008.[58]

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.

Laramie Rose – SpeedUp

Vehicle: Laramie Rose
Developer: SpeedUp
First Launch: TBD
Number of Stages: 1
Payload Performance: 25 kg (55 lb) to 50 m (165 ft)
Launch Site: TBD
Targeted Market: Lunar Lander Challenge competition

SpeedUp of Laramie, Wyoming, is developing the Laramie Rose vehicle to compete in the Northrop Grumman Lunar Lander Challenge competition. The vehicle, being built in partnership with Frontier Astronautics of Chugwater, Wyoming, is a vertical takeoff and vertical landing design powered by an engine using 90-percent concentration hydrogen peroxide. The vehicle is also designed to be a technology testbed for future rocket-powered recreational vehicles planned by the company. While Laramie Rose was not able to compete at the 2007 competition, the vehicle hardware is 99-percent complete and SpeedUp has performed static engine tests, and the company plans to compete in the 2008 competition.[59]


Laramie Rose

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

TGV Rockets, Inc. (TGV) is developing Michelle-B, a fully reusable, remotely-piloted sub-

Michelle B

orbital 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. Using existing optical packages, the vehicle can provide 60-centimeter oblique imagery. 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, in the second quarter of 2007, performed a test of their "work-horse" engine for the vehicle. The company is now working to complete a prototype engine based on the lessons learned from those tests.[60]

Crew Transfer Vehicle – Transformational Space LLC

Vehicle: Crew Transfer Vehicle (CXV)

Developer: Transformational Space LLC

First Launch: TBD

Number of Stages: 2

Payload Performance: Three people or 910 kg (2000 lb) to LEO

Launch Site: TBD (air launched)

Targeted Market: Crew and cargo to the ISS, orbital space tourism

Transformational Space (t/Space) LLC, of Reston, Virginia, has proposed developing the Crew Transfer Vehicle (CXV) reusable spacecraft, capable of carrying several people to the ISS or other destinations in low Earth orbit. The CXV would be air-launched by a scaled-up version of the QuickReach ELV being developed by AirLaunch LLC. The capsule design is derived from that developed for the Discoverer/Corona program nearly 50 years ago, and permits a safe reentry regardless of initial orientation even if the capsule's control systems fail. The CXV is designed to land in water and be reused after a nominal refurbishment.[61]

CXV

T/Space proposed the CXV during the initial COTS competition in 2006, but was not selected for a funded Space Act agreement. The company did sign an unfunded Space Act agreement with NASA in February 2007 to guide continued development of the CXV. T/Space submitted a proposal for the new COTS competition in November 2007.

Burning Splinter – Unreasonable Rocket

Vehicle: Burning Splinter

Developer: Unreasonable Rocket

First Launch: TBD

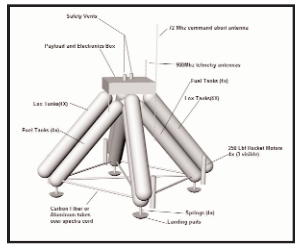
Number of Stages: 1

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

Launch Site: TBD

Targeted Market: Lunar Lander Challenge competition

Unreasonable Rocket of Solana Beach, California, is a father-son team developing the Burning Splinter vehicle to compete in the Northrop Grumman Lunar Lander Challenge. The vertical takeoff, vertical landing vehicle is powered by four engines using liquid oxygen and ethanol propellants. The team completed the vehicle hardware and performed some engine test firings, but was not able to get the vehicle ready to fly in time for the 2007 competition. Unreasonable Rocket is planning some modifications to the design to improve its performance for future competitions.[62]



Burning Splinter

Xerus – XCOR Aerospace

Vehicle: Xerus

Developer: XCOR Aerospace

First Launch: TBD

Number of Stages: 1

Payload Performance: 10 kg (22 lb) to LEO

Launch Site: Mojave Air and Space Port

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

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.

Xerus

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 with no flights having taken place. XCOR continues fundraising and technical development for the vehicle and anticipates filing a new license application for it when ready.

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, although it is devoting some resources to technology development that is relevant to RLVs. NASA has shifted its emphasis to developing large ELVs designed to implement the Vision for Space Exploration.

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: 1981

Number of Stages: 1.5

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

Launch Site: 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 120 launches since its introduction in 1981.

Space Shuttle

The three remaining orbiters—Atlantis, Discovery, and Endeavour—returned to flight in July 2005 after the loss of Columbia in February 2003. 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 role in constructing the ISS is complete. Thirteen Space Shuttle flights, including one mission to service the Hubble Space Telescope, are planned before the fleet is retired in 2010. The Space Shuttle’s day-to-day operations are managed by United Space Alliance, a Boeing-Lockheed Martin joint venture in operation since 1996.

Fully-Reusable Access to Space Technology Program

The Fully-Reusable Access to Space Technology (FAST) program is an effort by AFRL to develop technologies for use in RLVs capable of "aircraft-like" operations. FAST calls for the methodical development of these key technologies initially through ground experiments and later in flight tests, with the ultimate goal of flying a ground-launched suborbital vehicle capable of flying to speeds of Mach 4-7, as well as being capable of reentering at Mach 25 if launched as the upper stage of another vehicle. This experimental vehicle could be later scaled up to larger, operational vehicles. Current plans call for ground-based technology tests to continue through 2011, with first flights of the experimental suborbital vehicle slated for 2013.[63]

AFRL has issued contracts with several companies to work on elements of the FAST program. In March 2007, AFRL awarded Andrews Space a contract to develop the program requirements for a series of technology experiments that will be part of the overall effort.[64] In November 2007, Lockheed Martin Michoud Operations won a $14 million contract to work on airframe technologies, including composite structures and thermal protection systems, as a part of the FAST program.[65] In December 2007, AFRL awarded Northrop Grumman a 39-month, $5.2-million contract to study responsive ground operations and perform experiments and simulations to support the development of a future operations control center.[66]

Reentry Vehicles and In-Space Technology

A number of new orbital transportation systems are being developed by U.S. entities. These systems range from government reusable crewed and cargo vehicles to commercial habitats. These developments will provide critical manned and unmanned orbital operations and transportation in the post-Shuttle era after 2010. A number of technologies have been demonstrated for these systems during the past year and show progress towards planned operational capability.

NASA has development contracts for the civilian-use Orion crew exploration vehicle and one active award for commercial ISS crew and cargo demonstrations through the COTS program, with additional awards planned. The U.S. Air Force has plans for a military-use X-37B Orbital Transfer Vehicle (OTV) that will carry payloads into orbit. Finally, Bigelow Aerospace is in the process of developing commercial orbital habitats.

Orion Crew Exploration Vehicle

The U.S. plan for space exploration calls for continued missions to LEO and later missions to the Moon, Mars, and beyond. To achieve LEO, lunar, and other future missions, NASA has initiated the development of the Orion Crew Exploration Vehicle (CEV) to carry people and pressurized cargo into space. The spacecraft will consist of a combined pressurized crew module and service module that is launched into orbit by the Ares I crew launch vehicle. The current Orion design has the capacity to transport up to six crew members to the ISS or four people on missions to the Moon. The first flight of Orion carrying humans is to occur no later than 2015, and the first flight to the Moon is planned for no later than 2020. For missions to the Moon, an Orion capsule will rendezvous with an Ares V-launched lunar landing module and Earth departure stage in LEO to conduct its mission. At the end of these missions, Orion will be the atmospheric reentry vehicle.[67]

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. The capsule will reenter the atmosphere using a newly-developed thermal protection system. Other new technologies

Orion CEV

will include computing and electronics, a powered system for launch abort that will sit atop the Orion capsule (for which unmanned abort testing will commence in 2008), and landing technology.[68] 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.

Lockheed Martin is the prime contractor for the Orion crew vehicle under NASA's Constellation Program and led by the Orion Project Office at Johnson Space Center. NASA announced the prime contractor selection on August 31, 2006, and work has proceeded at the NASA centers and contractor locations. 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. Contracts for the lunar lander and earth departure stage have not yet been awarded.

Every NASA center has a role in the Orion mission. For example, Langley Research Center is the lead for developing the launch abort system, Glenn Research Center is leading the service module and spacecraft adapter development, and Marshall Space Flight Center and Kennedy Space Center will provide the Ares launch vehicles and Orion launch services, respectively.[69]

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 Shuttle retirement, after which Orion will provide this service. Russia’s Soyuz crew 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 (ATV) that are both currently in the development stage, with the first ATV planned for launch in early 2008.

American commercial vehicles are planned to supplement these government systems for crew and cargo transport to the ISS in the future. On August 16, 2006, NASA announced the signing of two funded Space Act Agreements with American companies to develop and demonstrate the ability to provide transportation services to the ISS, under the COTS demonstration program. One of these agreements, with Rocketplane Kistler (RpK), has since been terminated for failure to meet required milestones related to the development of its K-1 vehicle planned for orbital crew and cargo transport. The remaining company, SpaceX, has met its necessary deadlines and is building the Falcon 9 launcher and Dragon spacecraft to prove the necessary transport capabilities under Phase 1 of the agreement, which calls for three vehicle flights before 2010.

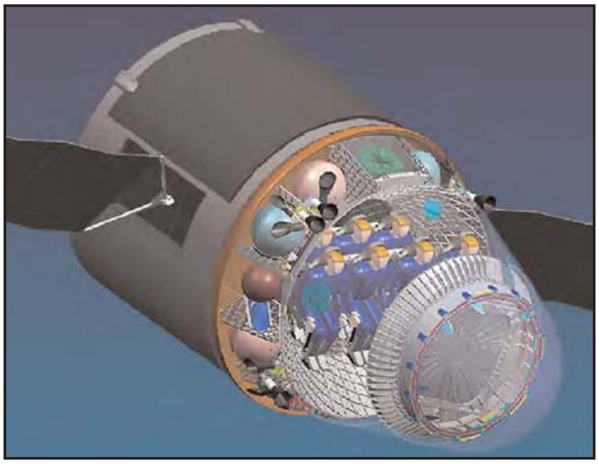
NASA is conducting a second competition for a funded COTS Phase 1 agreement to replace the terminaed 2006 agreement. This second competition commenced in October 2007 with a winner to be announced in February 2008. A total of $174.7 million—the remaining funds from the original agreement with RpK—will be made available to any winning company of the new competition. The COTS 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.[70]

SpaceX Dragon

Initiated internally by SpaceX in 2005, the Dragon spacecraft will be used for the commercial transportation of cargo and crew to and from LEO. As part of NASA's COTS program, SpaceX will conduct a series of three Falcon 9 launches to send a cargo-carrying Dragon into LEO where it will demonstrate the ability to maneuver, dock with the ISS, and return to Earth using a water landing. The first test flight of Dragon is planned for the second half of 2008, with subsequent launches over the following years.

The 4-meter (13-foot) diameter Dragon consists of two modules: the trunk and capsule. The unpressurized trunk module carries solar arrays, thermal radiators, and stowage area for unpressurized cargo. The capsule module consists of a nose cone to protect the vessel and docking adaptor during ascent, a pressurized section housing the crew and/or pressurized cargo, and a service section surrounding the base of the pressurized section and

SpaceX Dragon



Concept of SpaceX's Dragon vehicle with crew

containing avionics, reaction control system, parachutes, and other support infrastructure. The structural design of Dragon will be identical for cargo and crew missions, providing a capacity of over 2,500 kilograms (5,500 pounds) for launch and return in either configuration. In crew mode, the vehicle can carry up to seven people, and will be able to remain at the ISS for six months at a time, providing emergency return capability for the entire seven-person ISS crew. SpaceX has constructed full-scale engineering models of the capsule pressure vessel, heat shield, and other systems.[71]

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 announced that it also submitted a proposal for the new COTS competition in late 2007, with the intention of receiving funding for Dragon crewed capability.

Other Commercial Crew and Cargo Transport Concepts

NASA signed unfunded Space Act Agreements with five companies to help develop various vehicles and technologies that could lead to orbital crew and cargo missions in the future. These five companies, along with another that does not have a current Agreement, have created system development teams and submitted proposals for the new COTS Phase 1 competition.[72] These systems are planned to provide transport to the ISS and other orbital locations.

- Constellation Services International and Space Systems Loral (SS/L) have proposed a cargo system based on the SS/L LS-1300 satellite bus.

- PlanetSpace has teamed with Lockheed Martin Space Systems, ATK, and the Bank of Montreal to develop the Modular Cargo Carrier.

- SpaceDev's Dream Chaser Space Transportation System is a lifting body RLV that the company conceptually will launch on an Atlas V.

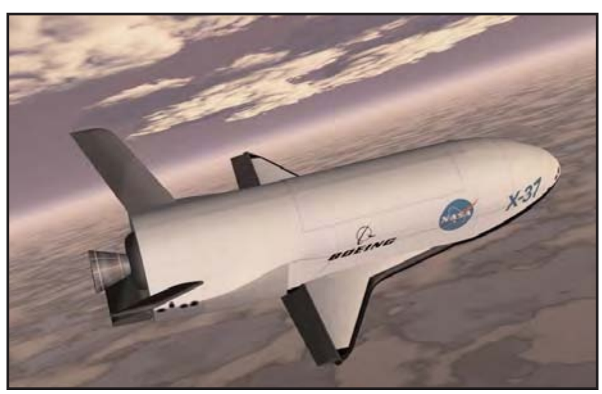
- SPACEHAB is proposing its Advanced Research and Conventional Technology Utilization Spacecraft (ARCTUS) for orbital transport.

- Transformational Space (t/Space) is devel oping the CXV Crew Transfer Vehicle, a transport and reentry vehicle based on Discoverer and Corona capsule design.

- Andrews Space, which does not have a current Space Act Agreement, proposed the Andrews Cargo Module logistics system.

X-37B Orbital Test Vehicle

The U.S. Air Force Rapid Capabilities Office is leading development of an unmanned reusable space vehicle designated the X-37B Orbital Test Vehicle (OTV). 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



Concept of X-37 vehicle, similar to X-37B in development

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 V in 2008. The vehicle will then deorbit and land on a runway at either VAFB or EAFB in California.[73] The first flights will be used for vehicle testing, after which operational technology experiment flights will be conducted.

Commercial Orbital Habitat Development

Bigelow Aerospace is developing next-generation, expandable space habitat technology that is intended to support a future private-sector-driven commercial space industry. The company has manufactured, launched, and is operating two technology demonstration spacecraft (Genesis I and Genesis II) that are validating the fundamental engineering concepts necessary to construct an expandable orbital habitat. Bigelow Aerospace is currently planning to construct and launch larger and more complex spacecraft over the next few years, all of which are being designed to support a crewed presence in LEO.

The Genesis II pathfinder spacecraft was launched on June 28, 2007, less than one year after the Genesis I launch on July 12, 2006. Both of these spacecraft were successfully orbited by an ISC Kosmotras Dnepr rocket launched from facilities at the new Yasny Cosmodrome in the Orenburg region of the Russian Federation. The two spacecraft are externally similar although internally different; Genesis II was outfitted with additional sensors, cameras, and unique interior payloads. The size of the demonstrators are approximately 4.4 meters (15 feet) in length and 1.6 meters (5.3 feet) in diameter at launch, expanding to 2.54 meters (8 feet) in diameter after full deployment is achieved in orbit. The spacecraft have a usable volume of 11.5 cubic meters (406 cubic feet) and an anticipated orbital lifespan of 3 to 13 years. Bigelow Aerospace uses its mission control facility in North Las Vegas, Nevada to operate these spacecraft.

Bigelow Aerospace will next continue its habitat development with the larger Sundancer spacecraft. The successful test and demonstration of technologies on the two Genesis spacecraft and the increasing cost of orbital launch has led Bigelow Aerospace to decide to proceed directly with the Sundancer, the company's first attempt at producing a habitat capable of supporting a human presence on orbit. The planned launch date for Sundancer is in approximately 2010. The spacecraft is currently anticipated to weigh around 8,600 kilograms (19,000 pounds) and offer roughly 180 cubic meters (6,350 cubic feet) of usable volume. The technologies to be demonstrated and deployed on Sundancer include environmental control and life support systems; guidance, navigation, and attitude control; propulsion; power generation; and windows. Subsequent to Sundancer, Bigelow Aerospace plans to launch a node/bus combination that will mate with the Sundancer to form the core of the company's first space complex. If this activity is successful, Bigelow Aerospace would then launch a full standard module that will also be attached to the Sundancer and node/bus complex.

External view of Genesis II

Conception of Bigelow modules

Bigelow Aerospace has executed agreements to explore relationships with various launch providers including Lockheed Martin and SpaceX for the possible use of the Atlas V or Falcon 9 vehicles, respectively, for future module and crew or cargo launches..

A critical issue for Bigelow Aerospace is the provision of transportation services to bring people and cargo to and from its platforms in LEO. The company would benefit from the availability of a low-cost and reliable commercial human-rated transportation system that could dock with Sundancer and future space complexes. For this reason, the company has created two initiatives to promote new vehicle development: the $50 million America's Space Prize (see the Space Prize Competitions section) and an offer to place $100 million in escrow to begin contracting for launch services that could reach a value of $760 million for twelve initial launches of various Bigelow Aerospace hardware.[74] This contract offer is an incentive for the development of new commercial orbital transportation systems, and for Bigelow Aerospace as it begins to develop plans for the mass production of its expandable, orbital habitats.[75]

Enabling Technologies

Organizations from industry and the government have been working to develop launch vehicle components that are substantially simpler, more flexible and reliable, and less costly than legacy technologies. These efforts research projects in the areas of air launch technologies, composite cryogenic fuel tanks, propulsion systems, thermal protection systems, and vehicle recovery systems. This chapter reviews some of the accomplishments made in 2007 with emphasis given to those organizations and technologies that have achieved significant testing milestones.

Microcosm Composite Tanks

Friction Stir Welding - Space Exploration Technologies Corporation

Space Exploration Technologies Corporation (SpaceX) uses friction stir welding during the construction of the Falcon 9 launch vehicle. The Falcon 9's first and second stage walls use a high-performance aluminum-lithium alloy. This is difficult and disadvantageous to weld with traditional techniques because the lightweight lithium vaporizes when melted, changing the alloy composition and producing a joint that is far weaker than the adjoining material. Friction stir welding forms a metal-to-metal joint without melting, using only friction and pressure. Thus, the alloy composition remains unaffected and retains its strength. This allows for the creation of some of the lightest and strongest possible metal alloy tanks.[76]

Falcon 9 first stage

Composite Tanks - Microcosm, Inc.

In 2007, Microcosm, Inc., of Hawthorne, California, continued development of a cryogenic composite LOX tank under SBIR Phase 2 funding. 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 Inc. of Lafayette, Colorado. 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). Microcosm's tank design and manufacturing method prevents gas permeation/leakage, and manages the typical micro-cracking that has always been the problem with all-composite tanks at cryogenic temperatures. The tank design 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. The composite tank is scheduled to be flight proven in early 2008.[77]

Solid Engines - Alliant Techsystems, Inc.

ATK was named the prime contractor by NASA for the development of the Ares I first stage in December 2005. The design of the Ares I first stage will primarily use existing Space Shuttle solid rocket motor technology; however, ATK is developing new components to increase performance. Improvements under development in 2007 include an enhanced propellant grain shape in the forward section of the motor and a larger diameter nozzle throat. The core tooling used to achieve the new propellant shape is in manufacturing.[78] Two mockups of a section located at the top of the motor between the first and second stages, called the forward skirt, have been constructed. The forward skirt mockups will simulate the physical space available for the avionics and will be used to determine the optimal required space and placement of the electronics.

Five-Segment Motor Test

In August 2007, ATK was awarded a multi-year $1.8 billion contract for the design, development, test and evaluation of the Ares I first stage. The multi-year contract extends through June 2013 and includes flight tests beginning in 2009. The flight test in 2009 designated Ares I-X, will utilize a modified four-segment Space Shuttle Solid Rocket Booster with a fifth segment simulator. Five ground tests of a new five-segment Ares I rocket motor are scheduled in 2009-2011. Three Ares I flight tests utilizing the new five-segment first stages are scheduled in 2012 and 2013.[79]

Liquid Engines - AirLaunch LLC

AirLaunch LLC, of Kirkland, Washington, is developing Vapor Pressurization (VaPak) LOX- and propane-powered upper stage engines for its QuickReach Small Launch Vehicle (SLV) as part of the Falcon SLV program..

AirLaunch LLC conducted a 191-second engine test in March 2007, the longest VaPak engine burn in history. As of November 2007, AirLaunch had conducted 55 test firings of its propulsion system, all using VaPak. The QuickReach second stage engine has been fired 50 times, totaling over 400 seconds, on the Horizontal Test Stand (HTS), in addition to several cold flow tests. Five test fires, totaling 315.5 seconds, have been performed on the Vertical Test Stand (VTS) with the QuickReach Integrated Second Stage (IS2), in addition to several propellant loading and conditioning tests.[80] The IS2 firings incorporated ground propellant loading operations and flight-type avionics, software, and systems. Transition of liquid oxygen to gaseous oxygen, a feature of VaPak, has been observed in test fires on both the HTS and VTS.

AirLaunch Hot Fire Test on VTS

In July 2007, DARPA and the USAF jointly agreed to fund Phase 2C at a value of $7.6 million. Phase 2C milestones include upgrades to hardware, instrumentation, and test stands; and a series of test fires on the HTS to gather data on engine performance and on the VTS to more comprehensively characterize second stage performance.[81]

Liquid Engines – Garvey Spacecraft Corporation

Garvey Spacecraft Corporation (GSC) is a small aerospace R&D company, formed in 1993, that is focusing on the development of advanced space technologies and launch vehicle systems. GSC conducts research and development in partnership with a variety of organizations. The most notable of these partnerships has been the California Launch Vehicle Education Initiative (CALVEIN) with California State University, Long Beach (CSULB). Since getting started in early

2001, the CALVEIN work has resulted in numerous static fire tests and 15 flight tests, including development of the CSULB aerospike engine as well as the more recent missions involving the prototype RLV test bed.

P-8A Static Fire Test

In September 2007, under the sponsorship of the U.S. Department of Labor and the California Space Authority's Workforce Innovation in Regional Economic Development (WIRED) program, the launch of Prospector 8A (P-8A) took place in the Mojave Desert. The primary goal of the flight was to test the new 20,000-newton (4,500-pound-force) thrust engine that GSC/CSULB has been developing for the past year. Programmatic objectives of the test included the creation of mentoring experiences in hardware development for aerospace students from CSULB, Stanford, and other WIRED partners, as well as the manifesting of payloads from academic, government, and commercial organizations. The flight of Prospector 8A ended prematurely when excessive fluttering resulted in failure of the stabilization fins. Lessons learned from the P-8 flight are now being applied by GSC to the development of the Prospector 9 prototype RLV under a Phase 2 SBIR with the Air Force. In 2007 GSC began practicing and evaluating water recovery techniques to expand the scope of their RLV operations. Present plans call for GSC to conduct a test flight in 2008.[82]

Liquid Engines – Northrop Grumman Corporation

Northrop Grumman successfully tested a new type of rocket engine specifically designed to use oxygen and methane propellants that range from all-gas to all-liquid at the inlet to the thruster. The new engine design was developed under contract to NASA Glenn Research Center's Cryogenic Reaction Control Engine program. The engine, dubbed the TR408, ensures that the fuel and oxidizer fully vaporize by passing the propellants through cooling passages located in the thrust chamber wall before injecting them into the chamber for combustion. This technique ensures consistent performance and combustion stability. Previous rocket engine designs using propellant to cool the chamber do not vaporize any of the propellant or may only vaporize one of the propellants, typically the fuel. The TR408 uses a simple design consisting of only two propellant valves, no moving parts other than the valves, and contains a built-in spark igniter to initiate combustion of the injected propellants.

Northrop Grumman announced in November 2007 that the TR408 had performed more than 50 separate tests demonstrating operating stability and an ample design margin for the 440-newton (100-pounds-force) engine. Upcoming test will attempt to operate the engine at a steady-state specific impulse of 340 seconds.[83]

Liquid Engines – Pratt & Whitney Rocketdyne, Inc.

NASA awarded Pratt & Whitney Rocketdyne, Inc. (PWR) a $1.2 billion contract in July 2007 to design, develop, and test a J-2X engine that will power the upper stage of the Ares I and Ares V launch vehicles. Powered by liquid oxygen and liquid hydrogen, the J-2X is an evolved variation of two historic predecessors: the J-2 upper stage engine, that propelled the Apollo-era Saturn IB and Saturn V rockets to the Moon in the 1960s and 1970s, and the J-2S, a simplified version of the J-2 developed and tested in the early 1970s but never flown. The J-2S turbopumps and related machinery were demonstrated in the 1990s on the X-33 aerospike engine. The J-2X main injector hardware, a major component of the engine, is similar to the J-2 engine injector. Engineers at NASA's Marshall Space Flight Center conducted hot-fire tests on subscale injector hardware in 2006 as part of an effort to investigate design options that would maximize performance of the J-2X engine for the Ares upper stages. The J-2X ignition system also will be a modified version of the system on the J-2 engine. Tests of an augmented spark igniter were conducted in 2006 at Marshall.[84] In December 2007, NASA began testing core components of the J-2X on the A-1 Test Stand at NASA's John C. Stennis Space

J-2 Awaits Testing on the A-1 Test Stand

Center near Bay St. Louis, Mississippi. The tests focused on the engine's powerpack a gas generator and turbopumps that perform the rocket engine's major pumping and combustion work. During the test, engineers ran liquid oxygen and liquid hydrogen through the powerpack, monitoring its ducts, valves, and lines to verify the tightness of seals in the oxidizer lines and pumps. All test objectives were met with no anomalies noted.[85]

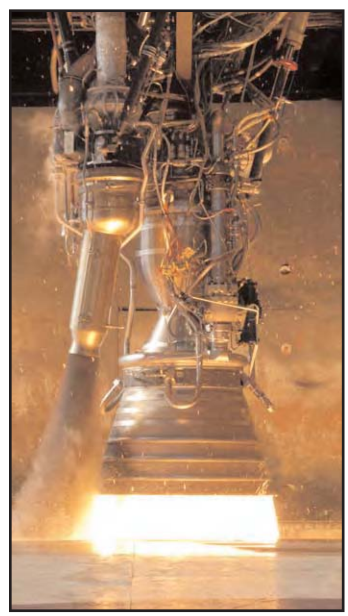
The J-2X will provide an estimated 1,308,000 newtons (294,000 pounds-force) of thrust to power the Ares vehicles. The contract includes ground and test flight engines and extends through December 31, 2012.[86] The first integrated J-2X engine systems test is scheduled for 2010.

Liquid Engines – Space Exploration Technologies Corporation

In 2006, SpaceX began working on the Merlin 1C engine, a regeneratively-cooled successor to the ablatively-cooled Merlin 1A engine. The regeneratively-cooled Merlin 1C uses rocket propellant grade kerosene (RP-1), a refined form of jet fuel, to cool the combustion chamber and nozzle before combining it with the liquid oxygen to create thrust. This cooling allows for higher performance without significantly increasing engine mass. The Merlin 1C engine will be used in upcoming Falcon 1 launches.[87] The Merlin 1C will also be used for the first and second stage of the Falcon 9.

During 2007, 125 hot fire tests were conducted on the Merlin 1C engine for a combined run time exceeding 3,000 seconds. In November 2007, SpaceX announced that it had completed development of the Merlin 1C.[88] In its current Falcon 9 first-stage configuration, the Merlin 1C has a thrust at sea level of 423,000 newtons (95,000 pounds-force), a vacuum thrust of over 480,000 newtons (108,000 pounds-force), vacuum specific impulse of 304 seconds and sea level thrust-to-weight ratio of 92. In generating this thrust, the Merlin 1C consumes 159 kilograms per second (350 pounds per second) of propellant. The chamber and nozzle are cooled by 45 kilograms per second (100 pounds per second) of kerosene. The kerosene is capable of absorbing 10 megawatts of heat energy. A planned turbopump upgrade in 2009 will improve the thrust by over 20 percent and the thrust to weight ratio by approximately 25 percent.[89]

The Merlin 1C engine will power SpaceX's next Falcon 1 mission, scheduled to lift off in early 2008. SpaceX's far larger Falcon 9 rocket, now in development, will employ nine Merlin engines on its first stage. A vacuum version of the Merlin 1C, with a larger bell nozzle and some additional features, will be used on the Falcon 9's upper stage.[90] In 2008, SpaceX targets to build approximately 50 booster engines, a number that exceeds the output of every country except Russia.[91]



Merlin 1C Test Firing

Liquid Engines – XCOR Aerospace Inc.

XCOR Aerospace, Inc. headquartered in Mojave, California, specializes in developing engines and propulsion systems for use on launch vehicles and spacecraft. In May 2006, XCOR won a contract from ATK to develop a 33,300-newton (7,500-pound-force) methane-fueled engine as a prototype for potential use on NASA's Orion spacecraft. The ATK-XCOR methane engine, also known as the 5M15, will build upon XCOR's existing engines. According to XCOR, the engine serves several purposes, including validation of key engine design elements, such as the regeneratively cooled chamber/throat assembly, the stability and performance of the injector, and the reliability of ignition. The 5M15 will incorporate a number of design features for safety and reliability, critical for human-rated applications, that were demonstrated on previous XCOR engine designs. Finally, the design is modular, facilitating rapid test of new components during development, and enabling modification for future exploration applications. Testing of the 5M15 began in Mojave in January 2007.[92] In November 2007, Time magazine recognized the potential of the 5M15 by making the methane-powered rocket an "Invention of The Year" award winner.[93] In December 2007, XCOR Aerospace and ATK announced the completion of testing on the 5M15.[94]

XCOR XR-5M15 Test Fire

In October 2007 at the X PRIZE Cup, video was shown of the first test flights of the Rocket Racing League's X-Racer vehicle. The X-Racer is propelled by an XCOR-developed 4K14 engine that produces 6,700 newtons (1,500 pounds-force) of thrust. The 4K14 uses a regeneratively-cooled LOX and pump-fed kerosene system. The X-Racer airframe is based on a Velocity airplane kit.[95]

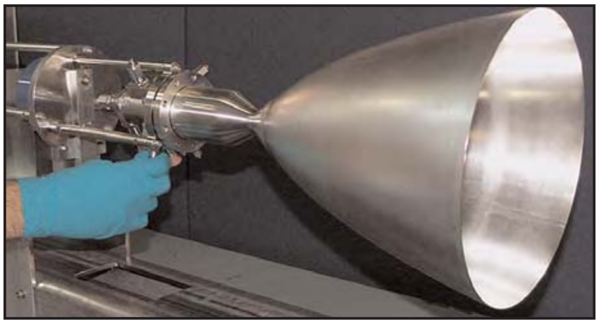
Liquid RCS Thruster – Orion Propulsion, Inc.

Orion Propulsion, Incorporated, of Huntsville, Alabama, announced in December 2007, the successful completion of the first series of hot-fire tests of a 440-newton (100-pound-force) oxygen-methane thruster module. Development of the thruster is funded by a NASA SBIR Phase 2 grant awarded in October 2006. The purpose of the thruster module project is to design, fabricate, and demonstrate the use of composite cryogenic tanks integrated into a propulsion system that is representative of future mission requirements, such as NASA's Orion Crew Exploration Vehicle, Lunar Lander, and long duration space missions. The system uses NASA-provided composite tanks, which have undergone extensive cryogenic testing with multiple cryogenic fluids, including liquid oxygen, liquid nitrogen, and liquid helium.

Orion Thruster Test

This engine offers 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.[96] The next step on the thruster module effort is to perform a series of extended storage tests on the cryogenic tanks. Orion and NASA will continue hot-fire testing of the module with gaseous and cryogenic propellants. The system will be operated under the conditions of a pressurized propellant system and under the conditions of saturated propellants operating in a blow-down mode.[97]

Liquid RCS Thruster – Space Exploration Technologies Corporation



Draco Thruster

SpaceX is developing a spacecraft thruster called Draco that generates 400 newtons (90 pounds-force) of thrust. The Draco thruster is fueled by a common aerospace bipropellant combination, monomethyl hydrazine and nitrogen tetroxide (MMH/NTO). The SpaceX Dragon crew and cargo spacecraft will have a total of 18 Draco thrusters for both attitude control and orbital maneuvering functions. Draco thrusters will also be used on the Falcon 9 second stage for maneuvering and deorbiting. In 2007, SpaceX's propulsion team completed the first Draco development engine, and in 2008 will begin testing at their new MMH/NTO test facilities in central Texas.[98]

Launch Abort System – Orbital Sciences Corporation

Orbital Science Corporation announced in September 2006 that it will build the Launch Abort System (LAS) for the NASA Orion CEV. Orbital is a member of the Lockheed Martin-led team selected to construct the Orion CEV and will receive approximately $250 million under subcontract to Lockheed Martin to construct the LAS.[99] The LAS will be composed primarily of solid rocket motors, separation mechanisms, canards, and an adapter structure. The LAS will provide escape capability for the Orion crew from pad operations through ascent. The new design, using Orbital's small launch vehicle technology, will improve flight crew safety as compared to current human space flight systems.

On November 14, 2007, NASA broke ground on a new test launch pad at the U.S. Army's White Sands Missile Range, N.M., that will be the site of a series of tests of a launch abort system for the Orion CEV. The first of five planned abort tests is scheduled from the new pad in September 2008. Two tests are planned to evaluate the performance of the launch abort system at ground level and three tests will evaluate its performance at different altitudes.[100] The contract calls for a five-year development program. Initial crewed flights to orbit are planned during the 2012 to 2014 time period, followed by a series of operational missions to the International Space Station and the Moon.[101]

Scramjet Propulsion – Pratt & Whitney Rocketdyne, Inc.

Pratt & Whitney Rocketdyne, Inc., along with its X-51A team members, including the U.S. Air Force, DARPA, NASA, and the Boeing Company, demonstrated operation and performance of the X-1 scramjet engine in the first simulated flight at Mach 5 of the X-51A. The X-1 demonstrator engine, designated the SJX61-1, is a hydrocarbon-fueled scramjet featuring X-51A flight hardware. The X-51A flight test program plans to demonstrate scram-

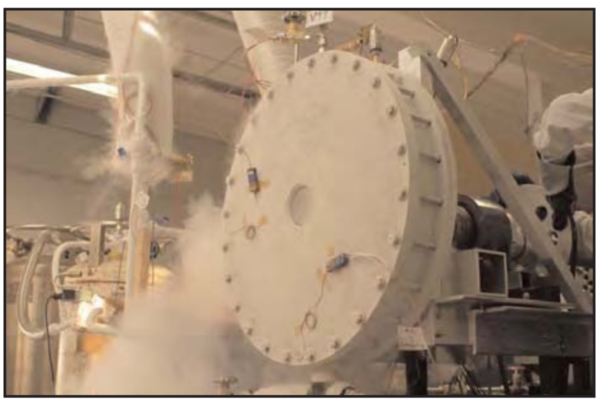
Conceptual Orion Launch Abort System

X-1 Scramjet Test

jet engine technology within the Mach 4.5-6.5 range with four flight tests beginning in 2009. According to PWR, the program will set the foundation for several hypersonic applications including access to space. Additional tests in early 2008 will verify engine performance and operability across the X-51A flight envelope.[102]

Propellant Production – Andrews Space, Inc.

Andrews Space, Inc., 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 cools it by passing the air through a series of heat exchangers cooled by both oxygen-depleted air and liquid hydrogen. Then, using a fractional distillation process, liquid oxygen is separated and stored in propellant tanks for use by liquid hydrogen and liquid oxygen rocket engines.



Andrews ACES Test

In March 2006, DARPA/AFRL awarded Andrews Space, Inc., 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 make significant program risk reductions. Development and demonstration of these technologies offers a hybrid approach to rocket propulsion, which can significantly reduce take-off gross weight.[103] In 2007, Andrews continued testing of the ACES system and successfully validated that rotary packing material could be used in the fractional distillation process at forces in excess of 1-G.[104]

Air Launch Method – AirLaunch LLC

QuickReach Drop Test

In July 2006, AirLaunch LLC dropped a full-scale simulated QuickReach rocket, weighing almost 33,000 kilograms (72,000 pounds) and measuring 20 meters (66 feet) in length, from an Air Force C-17 cargo plane 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 safely to 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.[105] The initial test in 2005 demonstrated the QuickReach release technology, including proof that the nose of the rocket does not hit the roof of the C-17A airplane as the booster leaves the carrier aircraft. The Falcon SLV program's Phase 2C includes a launch demonstration that could occur in 2008. AirLaunch did not conduct any further tests of the unique air launch system in 2007, instead focusing on development of propulsion systems for the QuickReach as detailed earlier in this chapter.[106]

Thermal Protection System – Andrews Space, Inc.

In December 2007, Andrews Space, Inc., announced the development and testing of new material for enabling advanced thermal protection systems. The tests, conducted at the NASA Ames Research Center arc-jet facility as part of a NASA

Phase 2 SBIR to develop lightweight ballute designs, identified new materials that can be used to enable thermal protection systems for non-rigid aerosurfaces. A ballute is a pressure-stabilized, inflatable membrane that provides a large, blunt, high-drag surface for aerobraking systems. Ballutes offer significant advantages over rigid shells for aerocapture and reentry of spacecraft by providing simplified packaging and lower total weight. Traditional ballute designs use several layers of Nextel fabric with insulating layers of Kapton and Kevlar structural backing. Andrews is developing lighter weight designs using thinner materials and transpiration cooling. The goal of the transpiration-cooled TPS design is to reduce the mass of the ballute TPS system by 20 percent over traditional, purely insulative solutions. Experimental data will be used to refine the ballute design and develop a concept to enable larger operational systems.[107]

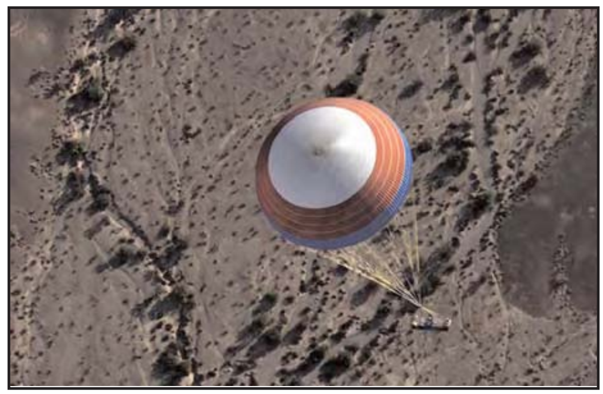
Thermal Protection System – Boeing

Boeing completed a developmental, 5-meter (16-feet) wide heat shield for NASA's Orion CEV in November 2007. The heat shield uses Phenolic Impregnated Carbon Ablator (PICA) material manufactured by Fiber Materials, Inc. of Biddeford, Maine, under contract to Boeing. PICA is a modern TPS material developed by NASA's Ames Research Center and has the advantages of low density coupled with efficient ablative capability at high heat flux. PICA is being considered for Orion's heat shield due to its proven performance on NASA's Stardust spacecraft heat shield. PICA's thermal characteristics will enable the CEV to survive the high reentry velocity associated with Earth reentry following a lunar mission.[108]

Prototype Heat Shield

Stage Recovery System – Alliant Techsystems, Inc. & United Space Alliance, LLC

ATK and United Space Alliance successfully tested in 2007 the world's largest rocket stage recovery parachute system. In September and November 2007, the 46-meter (150-foot) diameter, 900-kilogram (2,000-pound) parachute carried a 19,000-kilogram (42,000-pound) weighted test unit safely to the Earth.[109] The parachute is derived from the 41-meter (136-foot) main parachute currently used on the Space Shuttle Solid Rocket Boosters. The larger parachute will be used by the new five-segment solid rocket booster being developed for the Ares I first stage. The first Ares test flight, Ares I-X, a full-scale launch vehicle with inert upper stage, will use the new parachute. Ares I-X is scheduled to launch in April 2009.[110]



Parachute Testing at Yuma Proving Ground

Spaceports

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

While U.S. military and civil government agencies were the original and still are the primary users and operators of these facilities, commercial payload customers have become frequent users of federal spaceports. 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 launch or reentry sites, some of which are co-located with federal facilities. These spaceports serve both commercial and government payload owners.

Table 1 shows which states have non-federal, federal, and proposed spaceports. Figure 1 shows a map of U.S. spaceports and launch sites. Non-federal and federal U.S. spaceports capable of supporting launch and landing activities are described. A subsection detailing state and private proposals for future spaceports is also 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			✓

* Blue Origin utilizes an exclusive use launch site located in Texas.

Non-Federal Spaceports

While the majority of licensed launch activity still occurs at U.S. federal ranges, significant future launch and landing activity may originate from spaceports operated by private entities or state and local governments. For a U.S. person or institution that is a non-federal entity to operate a launch or reentry site in the U.S. or U.S. territories, it is necessary to obtain a license from the federal government through the FAA. To date, the FAA has licensed six non-federal launch sites. Three are co-located with federal launch sites, including the California Spaceport at Vandenberg Air Force Base, California; the Cape Canaveral Spaceport at Cape Canaveral Air Force Station, Florida; 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 Cape Canaveral Spaceport. Table 2 summarizes the characteristics of non-federal spaceports.

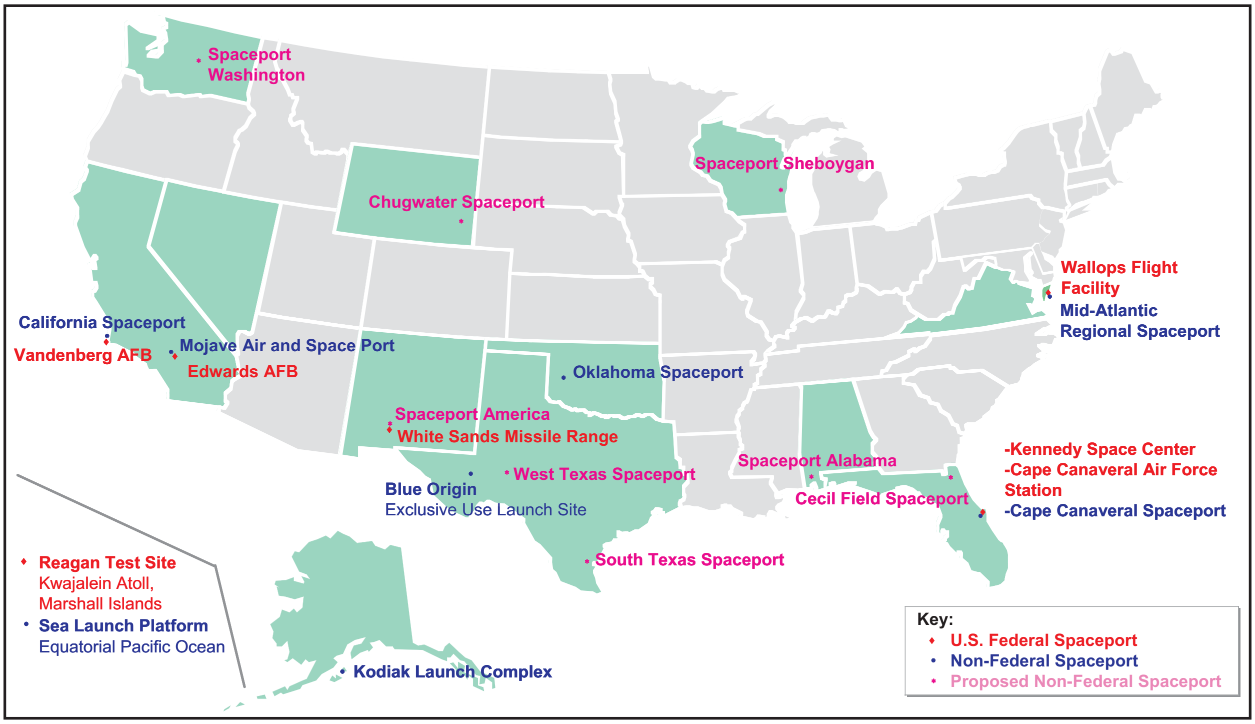
Blue Origin West Texas Launch Site

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 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 99,000 meters (325,000 feet). To conduct these operations, Blue Origin would construct a private launch site, including a vehicle processing

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. Subsequent flights followed in March and April 2007.
California Spaceport	Vandenberg AFB, California	Spaceport Systems International	Existing launch pads, runways, payload processing facilities, telemetry, and tracking equipment.	SLC 8 modified to support Minotaur IV.
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 a 5,200-m2 (50,000-ft2) RLV support hangar.	The quadra-axial static rocket test stand is under construction. It can accommodate engines up to 44,500 newtons (10,000 lbf) thrust.
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. 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.
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.	Site is operational. Currently it is conducting the planning and investigation of the expansion of capability to include heavier lift in support of commercial cargo to LEO operations.
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.	Infrastructure upgrades for 2007 were affected by the July 26 explosion. Funding has been received for the construction of a more reliable water delivery system that includes extension and upgrade of the water distribution system, as well as construction of an additional water storage tank. The construction is expected to be completed by spring 2008.
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. In June 2007, Armadillo launched the first flight under the new experimental permit rules from Oklahoma Spaceport.

Figure 1: U.S. Spaceports and Launch Sites



facility, launch complex, vehicle landing and recovery area, spaceflight participant training facility, and other support facilities.[111]

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 Commercial Space Launch Amendments Act of 2004. The vehicle to be tested will be unmanned and will be launched and landed vertically during tests. The permit granted to Blue Origin is a one-year, renewable permit, allowing for unlimited launches. Such permits are intended to allow launch vehicle developers to flight test their designs.[112] The first flight of Goddard, a subscale protype of the company's planned New Shepard vehicle, took place in November 2006; subsequent flights of Goddard took place in March and April 2007.

California Spaceport

On September 19, 1996, the California Spaceport became the first commercial spaceport licensed by the 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 34º North latitude, the California Spaceport can support a variety of mission profiles to low-polar-orbit inclinations, with possible launch azimuths ranging from 220° to 165°.

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 8 (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. During 2007, the spaceport has been upgrading both the IPF and SLC-8 to meet user requirements, and thus has not been able to support any launches from the SLC-8. The modifications for SLC-8 to support the Minotaur 4 launch system included upgrades to SLC-8 Mobile Access Tower and the Launch Equipment Vault (LEV).[113] The modifications were completed on schedule, in December 2007. The upgrades have been financed through USAF government contracts as well as private capitalization projects.[114] When fully developed, SLC-8 will accommodate a wide variety of launch vehicles, including the Minuteman-based Minotaur and Castor 120-based vehicles such as the Taurus.

California Spaceport SLC-8

California Spaceport supports satellite processing for launches at SLC-2, SLC-3, SLC-6, and SLC-8. Originally, the focus of the California Spaceport's payload processing services was on the refurbishment of the Shuttle Payload Preparation Room. Located near SLC-6, this large clean room facility was 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 II, Delta IV, and Atlas V payloads as well as smaller USAF and commercial payloads. During 2007, the spaceport supported processing of classified payloads in the IPF.

In 2001, SSI won a 10-year USAF satellite-processing contract for Delta IV class 4- and 5-meter (13- and 16-foot) payloads. This contract complements an existing 10-year NASA payload-processing contract for Delta II 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 2015. This contract covers Delta IV and Atlas V 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 II from SLC-2W at VAFB.

Cape Canaveral Spaceport

Space Florida was created on May 30, 2006, when then-Florida Governor Jeb Bush approved Florida House Bill 1489. Space Florida consolidates the state's previous space and aerospace entities and coordinates all space-related issues in Florida. 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.

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

Space Florida SLC-46 MAS

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. During 2007, Space Florida refurbished the LC-46 Mobile Access Structure. This was a $100,000 investment, financed through government appropriations.

As part of an overall effort to expand use of the Cape for research, development, and educational activities, Space Florida obtained a five-year license from the Air Force to use LC-47. This launch complex was upgraded to support a significant number of suborbital launch vehicles carrying academic payloads for research and training purposes. In May 2007, the construction of a quadra-axial static rocket motor test stand started. The stand will be capable of accommodating motors up to 30 centimeters (12 inches) in diameter, with a maximum average thrust of 53,400 newtons (12,000 pounds-force). The delivery of this system is expected in the spring of 2008.[115]

Space Florida's Strategic Business Plan recommends upgrading and marketing the commercial launch facilities at LC-46 at the Cape Canaveral Spaceport, developing a spaceport operating model to manage the Cape Canaveral Spaceport and other Florida spaceports, and providing economic incentive options to assist NASA COTS competitors.[116] During 2007, Space Florida has contracted with Reynolds, Smith, and Hills, an architecture, engineering and planning firm, to develop an update of its five-year Master Plan. The plan will be submitted to the Florida Department of Transportation (FDOT) and appropriate metropolitan planning organizations for review of inter-modal impacts and inclusion of eligible projects in FDOT's five-year work program. The update is expected to be completed by March 2008.[117]

The State of Florida has also developed the Customer Assistance Service Program for the Eastern Range (CASPER). This program is meant to provide no-cost professional consultant guidance to commercial launch service providers wishing to operate from the USAF Eastern Range and NASA Kennedy Space Center. CASPER provides guidance on how to complete requirements documentation and how to navigate the flight safety approval process in order to receive authorization to fly from the Eastern Range.[118]

Although no launches took place from Cape Canaveral Spaceport in 2007, Space Florida provided incentives to SpaceX as part of their NASA COTS efforts. The State of Florida was instrumental in SpaceX securing a five-year license from the USAF for LC-40 at CCAFS. Space Florida has provided over $600,000 worth of assistance to SpaceX through economic incentives such as office space, concept of operations design studies, and environmental studies. Using CASPER, Space Florida has also provided professional consultant services to SpaceX to guide it in the development of range documentation and flight safety systems to help it secure required launch approvals and authorization.[119]

In the future, Space Florida plans to incorporate a high-expansion foam fire-fighting system into the RLV support hangar. The Cape Canaveral Spaceport expects to receive between $7-10 million in direct appropriations to support its operations during fiscal year 2008.[120]

Kodiak Launch Complex

In 1991, the Alaska state legislature created the Alaska Aerospace Development Corporation (AADC) as a public company to develop aerospace-related economic, technical, and educational opportunities for the state of Alaska. In 2000, the AADC completed the $40-million, two-year construction of the Kodiak Launch Complex (KLC) at Narrow Cape on Kodiak Island, Alaska. The first

FTG-03 Launch from Kodiak Launch Complex 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 USAF, 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 eleven successful launches since 1998. Located at 57º North latitude, Kodiak Launch Complex occupies a 12.4-square-kilometer (4.8-square mile) site 438 kilometers (272 miles) south of Anchorage and 40 kilometers (25 miles) southwest of the city of Kodiak. The launch site itself encompasses a nearly five-kilometer (three-mile) area around Launch Pad 1. Kodiak provides a wide launch azimuth and unobstructed downrange flight path. Kodiak's markets are military launches, government and commercial telecommunications, remote sensing, and space science payloads weighing up to 1,000 kilograms (2,200 pounds). These payloads can be delivered into LEO, polar, and Molniya elliptical orbits. Kodiak is designed to launch up to Castor 120-based vehicles, including the Athena 1 and 2, and has been used on a number of occasions to launch military suborbital rockets.

The Missile Defense Agency (MDA) conducted target missile launches from KLC in February 2006, September 2006, May 2007, and September 2007. A five-year contract was signed in 2003 between the Missile Defense Agency (MDA) and AADC to provide launch support services for multiple launches in connection with tests of the nation's missile defense system.

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.

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.

Mid-Atlantic Regional Spaceport

The 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

NFIRE satellite mission launched from MARS inclinations and launch azimuths. Optimal orbital inclinations accessible from the site are between 38° and 60°; 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, Virginia and Maryland created a bi-state agreement to operate, conduct future development of, and promote the spaceport. The agreement also renamed the spaceport, previously called the Virginia Space Flight Center, to MARS.

MARS received $100,000 in July 2007 as fiscal year 2008 appropriation from Virginia. In addition, MARS benefits from the following incentives: state sales and use tax exemptions on all goods used, consumed or launched from MARS; state and local personal property tax exemption on machinery and equipment used as part of value added process for vehicles and payloads launched from MARS; state sponsored workforce training grants for new employees of aerospace companies working at or with MARS; state- and local-sponsored access to flex space in the industrial park adjacent to MARS; tort liability exclusion in Virginia courts resulting from personal space flight activities at MARS; state enterprise zone established at MARS to enable rapid access to infrastructure development grants. Also, VCSFA/MARS has bonding authority to issue state tax exempt development bonds.

CSC-DynSpace LLC currently operates MARS. In 1997, VCSFA signed a Reimbursable 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 with commercial customers to facilitate use of MARS facilities and services.

MARS has an official development plan, approved by the VCSFA Board of Directors. The plan was expanded in February 2007 to include the capability to process and launch heavier payloads and vehicles, such as those being developed in support of the NASA COTS initiative.[121] The spaceport is actively pursuing partnerships with space tourism companies and has an interest in supporting future RLVs, possibly using its launch pads or three runways at WFF.[122]

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 283,000 kilograms (624,000 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 cooperating with NASA WFF in the construction a $4-million logistics and processing facility in the Wallops Research Park that includes high bay and clean room environments. In conjunction with WFF, MARS constructed a mobile Liquid Fueling Facility capable of supporting a wide range of liquid-fueled and hybrid rockets. In 2007, MARS completed the upgrade of the class-100,000 high bay 1 of the new multi-purpose processing facility, as well as added environmental control systems to the launch pad 0-B Movable Service Structure. While the improvements to the high bay were in majority financed by the Federal government, the launch pad construction was financed from the spaceport revenue and cost approximately $100,000.[123] Future infrastructure improvement plans include enhanced capability for pad 0-B Movable Service Structure to accommodate additional launch vehicles.

Highlights for 2007 include the two orbital launches from launch pad 0-B within a four-month period. The first launch, of the USAF Space Development and Test Wing (SDTW) SDTW/AFRL TacSat 2 satellite, took place in December 2006, while the second one, of a USAF SDTW/MDA NFIRE satellite, happened in April 2007. The first launch was performed with only a five month call-up period for a launch vehicle never before launched from MARS (Minotaur I). MARS also contracted with NASA and the U.S. Air Force for the NASA ALV-X1 launch in February 2008 and for USAF SDTW/AFRL TacSat 3 launch in June 2008.[124] Another highlight for 2007 is the passing of the Spaceflight Liability and Immunity Act, Code of Virginia, Chapter 3, Title 8.01-227.8 *et.al.* in April of 2007.

Mojave Air and Space Port

Mojave Air and Space Port (formerly Mojave Airport) in Mojave, California, became the first inland launch site licensed by the FAA on June 17, 2004, allowing Mojave Air and Space Port to support suborbital launches of RLVs. The 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 Air and Space Port is owned and operated by the East Kern Airport District (EKAD), which is a special district with an elected Board of Directors and a General Manager.

Mojave Air and Space Port

Infrastructure at the Mojave Air and Space Port 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 worth of repairs to the airfield and taxiways were completed in November 2006. The cost of infrastructure upgrades totaled $10.5 million with 95 percent of the funding provided by the FAA and 5 percent by EKAD.[125]

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 were affected by the July 26 explosion during a cold-flow test of a nitrous oxide propellant system for SpaceShipTwo. The spaceport however received funding from the Economic Development Administration (EDA) to provide a more reliable water delivery system for fire protection beyond a single event occurrence. Such system includes extension and upgrade of the water distribution system as well as construction of an additional water storage tank. The construction is expected to be completed by spring 2008.

At the same time, Mojave is in the process of upgrading its Automated Weather Observing System (AWOS). The spaceport is also considering plans for a crash fire rescue response facility that would provide immediate support for RLVs that land with technical difficulties or crew medical emergencies.

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 AVTEL, 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 been part of two record-breaking events in this decade. 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 an airport in neighboring California City.[126]

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. 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. Besides state funding, NASA issued a $915,000 grant to OSIDA for aerospace education programs.

Oklahoma Spaceport

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, a rail spur, and 12.4 square kilometers (4.8 square miles) of open land. Existing buildings could serve to house spaceplanes, manufacturing facilities, and even a passenger terminal.[127] On July 13, 2007, the Oklahoma State Legislature approved $2 million in funding for upgraded security fencing and control tower improvements. Future development plans include enhancing the facility's operational control room and hosting phased-array radar tests.

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 edge of outer space.[128] 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.[129] Thus, this launch site became the first U.S. inland spaceport with an established fight corridor for space operations in the national airspace system clear of military operating areas or restricted airspace. This arrangement means that space vehicles will not need military permission to operate because the spaceport will have its own air space. The spaceport license was granted for five years.

The Oklahoma Department of Commerce offers several incentives to attract space-related businesses. For example, a jobs program provides qualifying companies with quarterly cash payments worth up to five percent of its new taxable payroll for up to ten years. Organizations also may qualify for other state tax credits, tax refunds, tax exemptions, and training incentives. Rocketplane Inc. and TGV Rockets, Inc. 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 qualified for an $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 Northrop Grumman Lunar Lander competition.[130] On June 2, 2007, Armadillo launched the first flight under the new experimental permit rules from a licensed spaceport. This flight performed a complete Lunar Lander Challenge Level 1 (LLC1) operational profile.

Federal Spaceports

Since the first licensed commercial orbital launch in 1989, the federal ranges have continually supported commercial launch activity in addition to handling government launch operations. 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. Cape Canaveral Air Force Station and VAFB host pads for the Delta II, Delta IV, and Atlas V.

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 3 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 is used to gather and process data on a variety of East Coast launches and deliver it to range users. To accomplish this task, the range consists of a series of tracking stations located at CCAFS, Antigua Air Station, and Ascension Auxiliary Air Field. The range also uses the Jonathan Dickinson and the Malabar Tracking Annexes on the Florida mainland. These stations may be augmented with a fleet of advanced range instrumentation aircraft as well as a site located in Argentia, Newfoundland.[131]

Cape Canaveral Air Force Station

Users of CCAFS include the USAF, Navy, NASA, and various private industry contractors. The ELTR also supports Shuttle launches from NASA KSC. With its mission partners, CCAFS processes a variety of satellites and launches them on Atlas V, Delta II, and Delta IV ELVs. The spaceport also provides support for the Space Shuttle program and U.S. Navy submarine ballistic missile testing.

During 2007, CCAFS supported Atlas V launches of Orbital Express, NRO L-30, WGS 1, and NRO L-24; the Delta II launches of THEMIS 1, Phoenix, Dawn, and NAVSTAR GPS 2RM-4 and 2RM-5; and one Delta IV Heavy launch of DSP 23.

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 lakebed, measuring about 114 square kilometers (44 square miles). Today, NASA uses KSC as the primary landing site for the Space Shuttle and uses EAFB as a backup site. EAFB 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.

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. During 2007, NASA signed a Space Act Agreement with Starfighters Inc. for simulated suborbital flight missions. Such missions would generate data relevant for the analysis of the environmental impact of suborbital and orbital commercial spaceflight from the SLF.
Reagan Test Site	Kwajalein Island, Republic of the Marshall Islands	U.S. Army	Telemetry, radars, and optical tracking systems, ship based telemetry/safety system, mission control facility, wideband CONUS connectivity, multiple safety systems and launch facilities, runway, warehouse and industrial use space, user and engineering office space.	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.
Wallops Flight Facility	Wallops Island, Virginia	NASA	Telemetry and tracking facilities, heavy jet-capable runway, launch pads, vehicle assembly and processing buildings, payload processing facilities, mobile liquid fueling facility under development range control center, blockhouses, large aircraft hangars, and user office and lab space.	Final certification of the Wallops Mobile Liquid Fueling Facility will be completed. Continued development of Payload Processing Facility High Bay is planned. Upgrades to MARS Pad 0-B to accommodate larger vehicles is under consideration.
White Sands Missile Range	White Sands, New Mexico	U.S. Army	Full telemetry and tracking facilities, runway engine and propulsion testing facilities, class-100 clean room for spacecraft parts.	Site is operational.

Within the last 10 years, EAFB has been the home of more than 10 experimental projects, among them the X-33 airplane. The X-33 launch site consisted of an X-33-specifc launch pad; a control center to be used for launch monitoring and mission control; a movable hangar where the vehicle was housed and serviced in a horizontal position; and hydrogen, nitrogen, and oxygen storage tanks. In 2006, three glide tests were successfully completed on the DARPA-sponsored X-37 autonomous research vehicle.

Shuttle landing at Edwards Air Force Base

Edwards completed an environmental assessment for reentry corridors to EAFB for lifting entry vehicles like the X-38 configuration.[132] An additional environmental assessment is being developed for corridors that will allow flight tests within the atmosphere for ranges of 741 kilometers (400 nautical miles) and 1,528 kilometers (825 nautical miles).

NASA Kennedy Space Center

Established as NASA's Launch Operations Center in July 1962, Kennedy Space Center today serves as the primary launch site for NASA's manned space missions. Major KSC facilities include Launch Complex 39, supporting Space Shuttle operations; the Vehicle Assembly Building (VAB), where the Shuttle is integrated; and the Shuttle Landing Facility. NASA KSC provides oversight of NASA's expendable launch vehicles that are flown primarily from CCAFS and VAFB with support from the USAF.

In September 2006, NASA KSC issued a Request for Proposals (RFP) for the selection of a master developer for a 129-hectare (319-acre) technology and commerce park at Kennedy Space Center. 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.[133]

Non-NASA use of KSC's Shuttle Landing Facility (SLF) increased during the last couple of years. In January 2006, the SLF was used by the GlobalFlyer airplane for a successful attempt to set a new world record for the longest flight made by any aircraft.[134] NASA and ZERO-G 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.[135] 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. In 2007 NASA and Starfighters Inc. signed a cooperative Space Act Agreement to enable the company's F-104 aircraft to fly simulated suborbital flight missions from the spaceport's space shuttle runway.

KSC launches Space Shuttle Discovery

The purpose of these flights is to gather data to support NASA's assessment of expanding uses of the SLF. The first in this series of pathfinder test missions took place in April 2007 and the flights generated "test data to validate sonic boom assumptions about the potential impacts of suborbital and orbital commercial spaceflight from the SLF. NASA is assessing the environmental impact of such flights."[137]

Reagan Test Site

Located at Kwajalein Atoll, part of the Republic of the Marshall Islands, the U.S. Army's Reagan Test Site (RTS) is part of the DoD Major Range and Test Facility Base (MRTFB). The advantages of RTS include its strategic geographical 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.

Interceptor launched from Meck2 at Reagan Test Site

A new launch pad on Omelek Island was constructed in 2006 to support space launch missions. The Army began deployment of a fiber optic communications system to the continental United States, to be completed in late 2009, along with a Huntsville, Alabama, Mission Control Center that supports net-centric distributed operations.[138]

With nearly 40 years of successful support, RTS provides a vital role in the research, development, test and evaluation effort of America's missile defense and space programs. At least 17 organizations, representing the military, academia, civil government, and commercial interests, use RTS.[139] Among the users, there are U.S. Army, Navy, Air Force, NSA, DOE, NRO, DARPA, Orbital Sciences, and SpaceX. The SpaceX launches of March 2006 and March 2007 were successfully supported at RTS, although payloads did not reach orbit. A Pegasus XL launch is scheduled from Kwajalein in 2008.

Vandenberg Air Force Base

In 1941, the U.S. Army activated this site near Lompoc, California, as Camp Cook. In 1957, Camp Cook was transferred to the Air Force, becoming the nation's first space and ballistic missile operations and training base. In 1958, it was renamed 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. 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 400-square-kilometer (155-square-mile) base also houses numerous government organizations and contractor companies. VAFB hosts a variety of federal agencies and attracts commercial aerospace companies and activities, including the California Spaceport effort. The 30th Space Wing supports West Coast launch activities for the USAF, DoD, NASA, MDA and various private industry contractors. VAFB 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.

Delta II preparing for launch at VAFB

Boeing has renovated Space Launch Complex 6 (SLC-6) from a Space Shuttle launch pad into an operational facility for Delta IV. 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 IV is assembled.

Lockheed Martin converted SLC-3E from an Atlas 2 launch pad into an operational facility for Atlas V. 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 II, Delta IV, Atlas V, Taurus, Minotaur, Pegasus XL, and Falcon 1. During 2007, VAFB supported three Delta II launches and one Pegasus XL launch. Orbital Sciences' Taurus is launched from 576E. Pegasus XL vehicles are processed at Orbital Sciences' facility at VAFB then flown to various worldwide launch areas. Vandenberg supports numerous ballistic programs, including Minuteman and numerous MDA test and operational programs. SpaceX maintains a launch pad at SLC-3 West for its Falcon 1 rocket, and plans future developments for its larger Falcon 9 rocket for sending commercial and government payloads into polar and other high inclination orbits.

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. VAFB houses three commercially owned complexes: Boeing's Horizontal Integration Facility, Spaceport Systems International's (SSI) California Spaceport and Payload Processing Facility, and Astrotech's Payload Processing Facility.[140]

Wallops Flight Facility

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

WFF's primary mission is to serve as a research and test range for NASA, supporting scientific research, technology development, flight testing, and educational flight projects. WFF, however, also heavily supports the 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 frequently serves as a downrange site for launches conducted from Cape Canaveral.

Wallops Flight Facility

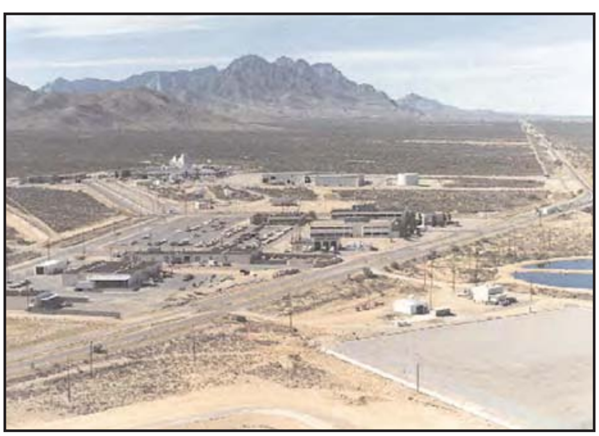
MARS is co-located at WFF as a tenant, and the organizations collaborate on certain projects to provide mission services, particularly focusing on small commercial ELVs. Jointly, WFF and MARS offer two orbital and several suborbital launchers, a range control center, three blockhouses, numerous payload 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.

WFF has continued a significant range modernization and technology program that began 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.[141] The Payload Processing Facility is operational and being used. The class-100,000 certification testing for the entire facility is pending, as only half the facility obtained this certification. The new project support facility, providing auditorium capabilities for large gatherings, including pre-mission reviews and observation of the launch, was completed in 2007.[142] The new engineering facility hosting WFF engineering staff and laboratories was also finished in 2007.[143] Final certification of the Wallops Mobile Liquid Fueling Facility is still to be completed. Future plans include a barge dock improvement to enable water transport between the Mainbase and the Island campuses.

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. During 2007, twelve suborbital and orbital rocket tests were conducted from WFF. WFF supported MARS with two orbital missions: the launch of the USAF and NASA TacSat 2 satellite in December 2006, and the NFIRE satellite in April 2007, each using a Minotaur I.

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 and used by the Army, Navy, Air Force, Marine Corps, and MDA. It is also 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 (3,127 square miles).



White Sands Missile range

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.[144] 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 suborbital rocket launch from Spaceport America in October 2006. WSMR provided tracking, communication and other services to support the suborbital space launch conducted by UP Aerospace in April, 2007.[145] Initially WSMR will provide a diversity of support services for Spaceport America, including flight safety, radar, optical tracking, and 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 – a contrast to the coastal location of all but two present-day U.S. spaceports – and interest in hosting RLV operations. Table 5 describes 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-meter (12,500-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, Jacksonville Aviation Authority (JAA) took ownership of 3,240 hectares (8,000

Table 5: 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-m (12,500-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).	The environmental assessment for spaceport operations was completed in 2007. FAA reviewed it and instructed JAA to initiate the launch site operator's licensing process. Discussions are currently underway to establish Airspace Agreements with FAA and the U.S. Navy. The Jacksonville Aviation Authority expects to submit an application for a launch site operator license in 2008.
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 and expected to be completed in 2008.
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 is in Port Mansfield, near Charles R. Johnson Airport. The interior of the building was finished in 2007.
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. While no land has been acquired for Spaceport Alabama, a green field site is under consideration in Baldwin County, across the bay from the city of Mobile.
Spaceport America	Upham, New Mexico	New Mexico Spaceport Authority	Major components of the proposed Spaceport America include two launch complexes, a landing strip, an aviation complex, and support facilities.	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 suborbital launch took place in September 2006, with another one following in April 2007.
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.

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. Space Florida has been instrumental in providing guidance and direction for the development of the Cecil Field Spaceport.[146] The JAA is pursuing a launch site operator's license. The environmental assessment needed for the issuance of the license was completed in 2007. The JAA expects to submit an application for a launch site operator license in 2008.

The existing infrastructure of this airfield is 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, an 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). The long runway, together with its location in a sparsely populated area and the proximity to the coast, make this site attractive for future commercial space activities. During 2007, JAA performed roof rehabilitation on six hangars and the terminal, structural upgrades and renovation of the air traffic control tower, and development of a new taxiway and an approach lighting system. JAA also conducted rehabilitation of the airfield electrical system, security fencing, and airfield pavement, as well as improvement in the stormwater drainage and fire suppression waterline. The construction and rehabilitation work JAA completed required an investment of over $9 million that came from FAA Discretionary Funds and Annual General Aviation Entitlements, as well as from the Florida Department of Transportation and JAA.

Cecil Field Aerial View

The plan is for Cecil Field Spaceport to use facilities that currently exist at the site. Future infrastructure planned for the facility includes pavement, fencing, stormwater plan, parking, access road improvements, and design and construction of an additional apron and of two additional hangars, each of 14,000 square meters (150,000 square feet). The hangars are scheduled for completion in 2008. The proposed spaceport operations, including horizontal launches and launch recoveries, will be conducted using Runway 18L/36R, which measures 3,810 meters (12,500 feet) in length and 60 meters (200 feet) in width.[147]

An official development plan focusing solely on the economic growth and operation of the Cecil Field Spaceport is currently being considered for development. The Cecil Field Airport Master Plan and Airport Layout Plan Update were completed in September 2007. These documents are currently under review by FAA, FDOT, and the City of Jacksonville, Florida.

Chugwater Spaceport

The Chugwater Spaceport 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. During 2007, several dozen test firings of rocket engines have occurred, as well as a completed flight vehicle test (the SpeedUp Laramie Rose Lunar Lander Challenge vehicle). All of these have taken place over the instrumented flame trench. The tests were possible because Frontier Astronautics obtained an exception to a countywide fire ban.

Chugwater Aerial View

So far, almost $600,000 has been invested in the site, all from private sources. The environmental assessment is expected to be completed in 2008 and Chugwater Spaceport will apply for an FAA license in 2008. No direct financial support is expected from the state. In 2007 X-L Space Systems has set up facilities in the spaceport and has started producing rocket-grade hydrogen peroxide for sale to other space companies. Plans for future infrastructure include a functioning 2,225,000-newton (500,000-pound-force) vertical test stand for engine testing, up to three vertical launch pads, on-site machine shop, and shooting range. An additional horizontal engine test area is in development. The planned configuration of the spaceport launch site is vertical launch pads with water acoustic suppression system.[148]

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 40.5-hectare (100 acre) 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. During 2007, the interior of the building with offices and bathrooms was completed. The State of Texas financed these efforts, which totaled to approximately $25,000. The launch barge for all launches still needs to be purchased.

Spaceport Alabama

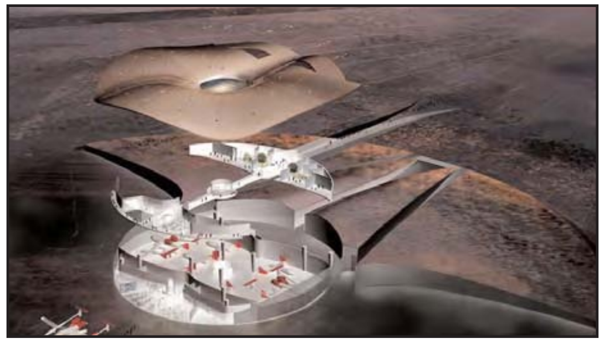
Proposed as a next-generation spaceport, Spaceport Alabama will be a full-service departure and return facility, supporting orbital and suborbital space access vehicles. Spaceport Alabama is in the planning phase under direction of the Spaceport Alabama Program Office at Jacksonville State University in Alabama. Phase 1 of the Spaceport Alabama master planning process is now complete, and phase 2 has commenced. Upon completion of the Spaceport Alabama master plan, 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.[149]

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 turnkey 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. The spaceport hopes to continue development as industry opportunities emerge.

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 Virgin Galactic in New Mexico and use Spaceport America as its primary operating base. He also entered into 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.[150] The spaceport is planned to receive $140 million as direct financial support from the state and $58 million as direct financial support from local government, beginning with 2008.[151]

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 created one entity, New Mexico Spaceport Authority, to oversee the spaceport. Spaceport America is currently taking steps to obtain an FAA launch site operator license. The state owns and operates the spaceport and will lease the facilities to the users. Currently, agreements are being developed with different organizations.[152] 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.[153] 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.[154]



Cutaway View of Spaceport America facility

During 2006, 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; the funding came from private and government sources. Major components of the proposed Spaceport America 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 2008, and having a full-fledged spaceport to support vertical launches, vertical landings, and horizontal landings by 2010.[155] 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.

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.[156]

The first launch from the spaceport took place on September 25, 2006, when UP Aerospace launched an amateur-class vehicle. On April 28, 2007 UP Aerospace launched another amateur-class vehicle, SL-2. The commitment in building the spaceport, the recent activities there, and state incentives to locate space-related businesses in New Mexico have made the state an attractive location for rocket activity, such as Starchaser Industries, the X PRIZE Cup, and the Rocket Racing League.

Spaceport Sheboygan

On August 29, 2000, the Wisconsin Department of Transportation officially approved creating the Spaceport Sheboygan, 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 2007. Rockets for Schools is a program of the Great Lakes Spaceport Education Foundation.

Rocket launch from Spaceport Sheboygan

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 2007, under the Rockets for Schools program, more than 45 rockets were launched off of the pier. In 2006 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 2007.

Legislation for the creation of the Wisconsin Aerospace Authority (WAA) was signed into law in 2006. WAA will meet for the first time in January 2008. WAA will design, develop, and operate the spaceport. The board was created to market the state to the aerospace industry, develop space-related tourism, and work with educators to promote math and science classes with a greater focus on aeronautics and engineering.[157] The legislation authorizes the WAA to develop spaceports, spacecraft, and other aerospace facilities in Wisconsin; provide spaceport and aerospace services; allow use of spaceport and aerospace facilities by others; promote the aerospace industry in Wisconsin; and provide public-private coordination for the aerospace industry in Wisconsin.[158] In addition to designing, developing, and operating the spaceport, WAA is authorized to sell up to $100 million in revenue bonds.[159]

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 Spaceport Sheboygan. Once the legislation is approved, WAA will conduct site evaluation, feasibility, and environmental impact studies. Project supporters are in the initial stages of obtaining an FAA launch site license.[160] Future projects include adding orbital launch capabilities for RLVs, including a horizontal and vertical launch site.

Spaceport Washington

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 horizontal and vertical take-offs and horizontal landings of all classes of RLVs. This airport has a 4,100-meter (13,452-foot) main runway and a 3,200-meter (10,500-foot) crosswind runway and is certified as an emergency landing site for the Space Shuttle. 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.[161]

An approximately 121-square-kilometer (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.[162] At present, Spaceport Washington is seeking launch operators. It will not apply for an FAA launch license until it has viable operations and a business plan.[163]

Spaceport Washington Aerial View

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), payload integration and launch control facilities, and the Pecos County Airport runway (2,310-meters or 7,500 feet) and hangar complex. The site has access to over 1,740 square kilometers (4,500 square miles) of unpopulated land and over 3,860 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 currently are operators of unmanned air systems.

A joint project with the school district has made a 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 a vehicle's flight up to tens of thousands of feet (depending upon the size of the vehicle) regardless of its speed.[164] 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.

Future infrastructure plans include the development of a privately-funded 1,077-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.[165]

Regulatory Developments

In 2007, the FAA continued to enhance and refine its regulations in three primary areas—private human spaceflight, experimental launches, and amateur rockets—in ways that balanced promotion of a vigorous U.S. commercial space industry with the need to safeguard the public. This section reviews the most recent regulatory developments in these three areas. As this section is a summary, the FAA recommends that readers interested in further details consult the regulatory documents in their entirety, available online at http://ast.faa.gov.

Private Human Space Flight

On December 23, 2004, the President signed into law the Commercial Space Launch Amendments Act of 2004 (CSLAA). The CSLAA promotes the development of the emerging commercial space flight industry and makes the Federal Aviation Administration (FAA) responsible for regulating commercial human space flight. Recognizing that this is a fledgling industry, the law required a phased approach in regulating commercial human space flight, with regulatory standards evolving as the industry matures.

On December 15, 2006, the FAA issued regulations establishing requirements for crew and space flight participants involved in private human space flight. The new rules, which became effective on February 13, 2007, maintain FAA's commitment to protect the safety of the uninvolved public and call for measures that enable space flight participants to make informed decisions about their personal safety. The CSLAA characterizes what is commonly referred to as a passenger as a "space flight participant." The statute defines this person to mean "an individual, who is not crew, carried within a launch or reentry vehicle." This characterization signifies that someone on board a launch or reentry vehicle is not a typical passenger with typical expectations of transport, but instead someone going on an adventure ride.

The regulations require launch vehicle operators to provide certain safety-related information and identify what an operator must do to conduct a licensed launch with a human on board. In addition, launch operators must inform passengers of the risks of space travel generally and the risks of space travel in the operator's vehicle in particular. These regulations also include training and general security requirements for space flight participants.

The regulations also establish requirements for crew notification, medical qualifications and training, and requirements governing environmental control and life support systems. In particular, the regulations require a pilot of a launch or reentry vehicle to possess and carry an FAA pilot certificate with an instrument rating. Each crew member with a safety-critical role must possess and carry an FAA second-class airman medical certificate. The regulations require an operator to verify the integrated performance of a vehicle's hardware and any software in an operational flight environment before allowing any space flight participant on board. Verification must include flight testing.

Since the human space flight regulations were issued, the FAA has begun to develop advisory circulars or guidance documents in the areas of human space flight crew training and environmental control and life support systems (ECLSS) for suborbital missions. These documents will provide guidance and acceptable means of meeting some of the human space flight regulations pertaining to crew training and ECLSS.

Finally, the regulations establish financial responsibility and waiver of liability requirements to human space flight and experimental permits in accordance with the CSLAA. The CSLAA requires crew and space flight participants to enter into a reciprocal waiver of claims with the U.S. government. Furthermore, the CSLAA expressly excludes space flight participants from eligibility for indemnification against third party claims. Launches and reentries performed pursuant to a permit are also excluded from eligibility for indemnification.

Experimental Launch Permits

A number of entrepreneurs are committed to the goal of developing and operating reusable launch vehicles for private human space travel. In order to promote this emerging industry and to create a clear legal, regulatory, and safety regime, the

2004 CSLAA also established an experimental permit category for launching developmental reusable suborbital rockets on suborbital trajectories.[i] The FAA issued regulations implementing this alternative to a license on April 6, 2007. This section details eligibility requirements for experimental permits, notes how they differ from licenses, and discusses how they are implemented and administered.

Eligibility

To be eligible for an experimental permit, an applicant must propose to fly a reusable suborbital rocket for the following purposes:

- Research and development to test new design concepts, new equipment, or new operating techniques;
- Demonstration of compliance with require ments as part of the process for obtaining a license; or
- Crew training before obtaining a license for a launch or reentry using the design of the rocket for which the permit would be issued.

Experimental Permit Compared to a License

An experimental permit differs from a license in several ways, including the following:

- The FAA must determine whether to issue an experimental permit within 120 days of receiving an application. For a license, it is 180 days.
- Under a permit, a reusable suborbital rocket may not be operated to carry property or human passengers for compensation or hire. No such restriction applies for a license.
- Damages arising from a permitted launch or reentry are not eligible for "indemnification," the provisional payment of claims under Chapter 701. Damages caused by licensed activities, by contrast, are eligible for the provisional payment of claims to the extent provided in an appropriation law or other legislative authority.
- A permit must authorize an unlimited number of launches and reentries for a particular reusable suborbital rocket design. Although a license can be struc-tured to authorize an unlimited number of launches, no statutory mandate to do so exists.
- Under a permit, a launch operator is not required to demonstrate that the risk from a launch falls below specified quantitative criteria for collective and individual risk. Under a license, a launch operator must.
- Under a permit, a launch operator is not required to have a separate safety organization or specific safety personnel. Under a license, a launch operator must.

Safety Measures

The experimental permit regulations include a variety of safety measures to protect the public. The most important is an applicant-derived hazard analysis. A hazard analysis is a system safety engineering tool that identifies and characterizes hazards and qualitatively assesses risks. An applicant for a permit must perform a hazard analysis and provide the results to the FAA. A permit applicant uses this analysis to identify its risk elimination and mitigation measures to reduce risk to an acceptable level. An applicant must show that selected risk elimination and mitigation measures will work. Applicants may demonstrate this through providing flight demonstration test data; component, system, or subsystem test data; inspection results; or analysis.

Using the hazard analysis, most safety solutions are derived by the launch operators themselves. The regulations do, however, contain a num-

[i] The CSLAA defines a suborbital rocket as a vehicle, rocket-propelled in whole or in part, intended for flight on a suborbital trajectory, whose thrust is greater than its lift for the majority of the rocket-powered portion of ascent. A suborbital trajectory is defined in the CSLAA as the intentional flight path of a launch vehicle, reentry vehicle, or any portion thereof, whose vacuum instantaneous impact point does not leave the surface of the Earth.

ber of operating requirements that the FAA believes are too important to omit. These include:

- Rest rules for vehicle safety operations per sonnel
- Pre-flight and post-flight operations
- Operating area containment
- Key flight-safety event limitations
- Landing and impact locations
- Agreements with other entities involved in a launch or reentry
- Collision avoidance analysis
- Tracking a reusable suborbital rocket
- Communications
- Flight rules
- Anomaly recording and reporting
- Mishap reporting, responding, and investi gating

Operating area containment, key flight safety event limitations, and anomaly reporting are discussed below.

Operating Area Containment

Central to the experimental permit approach is containment of the reusable suborbital rocket within one or more defined operating areas. A permit applicant must define an acceptable operating area, and must demonstrate to the FAA that it can contain its reusable suborbital rocket's instantaneous impact point (IIP)[ii] within the operating area and outside any FAA-defined exclusion area.[iii]

An operating area is a three-dimensional region meeting the following criteria:

- Must be large enough to contain each planned trajectory and all expected vehicle dispersions;
- Must contain enough unpopulated or sparsely populated area to perform key flight-safety events, discussed below;
- May not contain or be adjacent to a dense ly populated area or large concentrations of members of the public; and
- May not contain or be adjacent to signifi cant automobile traffic, railway traffic, or waterborne vessel traffic.

The above criteria are designed to prohibit the operation of a reusable suborbital rocket over areas where the consequences of an uncontrolled impact of the vehicle or its debris would be catastrophic. Note that agreements with FAA Air Traffic Control would also influence the size and location of an operating area. Although conditions on the ground may be favorable for flight test, airspace concerns may limit the feasibility of an otherwise acceptable operating area.

During the application process, an applicant must identify and describe the methods and systems used to contain its reusable suborbital rocket's IIP within the operating area and outside any exclusion area. Acceptable methods and systems would include but not be limited to:

- Proof of physical limitations on a vehicle's ability to leave the operating area; and
- Abort procedures and safety measures derived from a system safety process.

Proof of physical limitations on a vehicle's ability to leave the operating area could be obtained through an analysis that showed that the maximum achievable range of the reusable suborbital rocket from the launch point was within the boundaries of the operating area, assuming the rocket flew a tra-

[ii] An IIP is an impact point, following thrust termination of a launch vehicle, calculated in the absence of atmospheric drag effects.
[iii] An exclusion area is an FAA defined area on the ground that warrants special protection for safety or policy purposes.

jectory optimized for range and that all safety systems failed.

An applicant could use its hazard analysis to determine safety measures to keep a reusable suborbital rocket's IIP within its operating area. Alternatively, an applicant could perform a separate and more comprehensive system safety analyses solely for containment. Specific safety measures obtained from a system safety process could include a dedicated flight safety system or systems and procedures that, while not dedicated exclusively to flight safety, help to protect the public.

Key Flight-Safety Event Limitations

Operating within an acceptable operating area and implementing safety measures obtained from a hazard analysis are only part of what would be necessary to maintain public safety. Because of the uncertainty in operating developmental reusable suborbital rockets, a permittee must conduct "key flight-safety events" over unpopulated or sparsely populated areas. A key flight-safety event is a permitted flight activity that has an increased likelihood of causing a failure compared with other portions of flight. Events such as rocket engine ignition, staging, and envelope expansion have historically had the highest probability of catastrophic failure for rocket-propelled vehicles.

Anomaly Reporting

Analyses of mishaps often show that clues existed before the mishap in the form of anomalies during the project life cycle. Examination and understanding of launch vehicle system and subsystem anomalies throughout the life cycle can warn of an impending mishap and can provide important information about what conditions need to be controlled to mitigate public risk. Because of this, the FAA has placed special emphasis on anomaly reporting in the experimental permit regime.[iv]

A launch operator must record anomalies and, after analyzing the root cause of each anomaly, implement corrective actions for those anomalies. This would promote informed safety decisions by a launch operator. An operator must also report to the FAA certain safety-critical anomalies.

Guidance Documents

The FAA has developed a number of guidance documents to assist permit applicants. These include the following:

- AC 437.55-1, Hazard Analysis for the Launch or Reentry of a Reusable Suborbital Rocket Under an Experimental Permit (April 20, 2007)
- AC 437.73-1, Anomaly Reporting and Corrective Action for a Reusable Suborbital Rocket Operating Under an Experimental Permit (April 20, 2007)
- Sample Experimental Permit Application for a Vertical Launch and Landing Reusable Suborbital Rocket, Version 1.1, April 2007
- Guide to Software Safety Analysis, Version 1.0, June 2006

Summary

The FAA has attempted to craft a regulatory regime that is conducive to developmental rocket test flights but still protects public safety. Although streamlined compared to a license, the experimental permit regime places great emphasis on a hazard analysis to identify hazards and reduce risks, operating area containment, limitations on the most hazardous activities, and tracking of anomalies.

Amateur Rocket Classes

Although the term amateur rocket conjures images of young children and their parents launching model rockets from baseball fields, in fact the FAA definition also includes rockets of considerably more weight and impulse, some capable of flying to altitudes of 7,600 meters (25,000 feet) or higher. FAA Order 7400.2F provides the Office of Commercial Space Transportation authority to review rocket activities where the maximum alti-

[iv] An anomaly is an apparent problem or failure that affects a system, a subsystem, a process, support equipment, or facilities, and that occurs during verification or operation.

tude achieved is greater than 7,600 meters (25,000 feet) above ground level (AGL). Under this order, the FAA has the responsibility to regulate unmanned rockets to ensure the safety of aircraft flying nearby and the safety of persons and property on the ground.

The FAA issued the first regulations applying to unmanned rocket operations in 1963. These regulations required amateur rocket operators to provide advance notice to the FAA, and made such launches subject to FAA approval. Amateur rockets have grown bigger and now fly higher and farther compared to when those first regulations were published. They now have a greater potential of creating hazards beyond their launch points. As rocket technologies have changed, regulations have been amended to accommodate them—first in 1988, and later in 1994.

The most recent round of amateur rocket regulatory changes was set in motion on June 14, 2007, when the FAA published a Notice of Proposed Rulemaking (NPRM) in the Federal Register. This action proposed a number of changes in FAA's regulations for unmanned rockets aimed at preserving the safety of amateur rocket activities, addressing inconsistencies in the current regulations, and improving the clarity of the regulations. The public was invited to comment on the proposed changes. As of late 2007, the FAA was considering the public comments it received to determine how and when it may issue a final rule.

What the FAA Proposed

Under the June 2007 NPRM, the FAA proposed adding two new categories of amateur rocket operations and amending the definitions of the existing two categories. As such, the new category structure would be numbered from Class 1 to Class 4. The two new categories would be Class 3 (high-powered rockets) and Class 4 (advanced high-power rockets). These two new categories capture amateur rockets that require significant analyses on the part of the FAA to determine if they can be safely launched and what operational constraints might be necessary to preserve public safety. The Class 1 and Class 2 rocket categories, meanwhile, would be slightly modified to incorporate more current definitions of model rocket and large model rocket, respectively. Further description of these categories follows below.

Class 1–Model Rockets

The proposed Class 1-Model Rockets would be defined as amateur rockets using less than 125 grams (4.4 ounces) of slow-burning propellant, made primarily of paper, wood, or breakable plastic, containing no substantial metal parts, and weighing no more than 454 grams (16 ounces), including the propellant. This updated definition differs from the existing definition in two ways: maximum propellant weight and operating limitations. The maximum propellant weight would be increased from the existing 113 grams (4 ounces) to 125 grams (4.4 ounces). Additionally, Class 1-Model Rockets would have to be "operated in a manner that does not create a hazard to persons, property, or other aircraft."

Class 2–Large Model Rockets

The proposed definition of Class 2-Large Model Rockets would only differ from Class 1 in terms of maximum total weight. Class 2 would continue to allow rockets weighing up to 1,500 grams (53 ounces), including propellant, in contrast to the 454 grams (16 ounces) covered by Class 1.

Class 3–High-Power Rockets

Class 3-High-Power Rockets would be defined as amateur rockets other than model rockets or large model rockets that are propelled by a motor or motors having a combined total impulse of 163,840 N-sec (36,818 lb-sec) or less. In terms of motor class, this qualifies as a "Q motor." The FAA would use total impulse as the distinguishing criterion for high-power rockets because total impulse is a good measure of the size, power, and performance of the rocket.

Rockets that would be considered Class 3 under the new definition currently operate under the provisions for Large Model Rockets. These limitations would remain unchanged, but two more limitations codifying current practice would be added. The first of the new limitations would be that a person at least 18 years old must be present and in charge of ensuring the safety of the operation. The second new limitation would require reasonable precautions be available to report and control a fire. (Although this is a current practice, it would be codified under the proposed rulemaking.)

Class 4–Advanced High-Power Rockets

Class 4-Advanced High-Power Rockets would include any amateur rockets that do not fall under one of the other three classes definitions. In general, these would be rockets with a combined total impulse above 163,840 N-sec (36,818 lb-sec), that is, a Q motor. However, the regulation would be written such that other, unforeseen operations or advancements in amateur rocket technology will be captured as Class 4.

The risk to the public from launches of this category is often higher due to the larger amount of propellant or stored energy within the vehicle. This higher risk factor requires greater scrutiny. As such, Class 4 would capture rockets more powerful than those typically launched at amateur high-power rocket events.

The proposed rule does not impose any additional limitations on operating Class 4-Advanced High-Power Rockets; however, the FAA may specify operating limitations necessary to ensure that air traffic is not adversely affected and public safety is not jeopardized.

Information Requirements

Information requirements define data required by the FAA to determine if a rocket can be safely launched. Due to the low risk posed by Class 1 – Model Rockets, operators of this class of rocket would continue to be exempt from information requirements. Operators of Class 2 – Large Model Rockets would continue to provide Air Traffic Control with their names and addresses, the highest anticipated altitude, the location of the launch, and the date, time, and duration of the launch event. Air Traffic Control would then be in a position to notify aircraft flying nearby of the rocket launches.

Under the NPRM, the FAA has proposed to codify reporting practices for the new categories of Class 3 and Class 4 rockets. Rockets in these classes currently file for a waiver to conduct their launches. They are then exempt from launch license regulations. Once the FAA receives the waiver application, they usually contact the operator for additional information. However, under the NPRM, all information would be gathered during the initial waiver application. Thus both the FAA and the operators could save time and expense.

Next Steps

The FAA is now reviewing the comments received on the NPRM. Some of these contain suggestions for changes that amateur rocket operators and others wish to see implemented before the rule becomes final. When and if these proposed new amateur rocket rules become final, the FAA will publish them in the Federal Register.

Endnotes

1 Google Lunar X PRIZE Competition Guidelines webpage. X PRIZE Foundation. Accessed 19 November 2007. http://www.googlelunarxprize.org/lunar/competition/guidelines.

2 Communication with SpaceX, 27 November 2007.

3 "Armadillo Aerospace Nearly Wins Northrop Grumman Lunar Lander Challenge." 28 October 2007. X PRIZE Foundation press release. Accessed 19 November 2007. http://www.xprize.org/llc/press-release/armadillo-aerospace-nearly-wins-northrop-grumman-lunar-lander-challenge.

4 Communication with Bigelow Aerospace, 7 December 2007. Also see America's Space Prize webpage. Bigelow Aerospace. Accessed 20 November 2007. http://www.bigelowaerospace.com/multiverse/space_prizeb.php.

5 Centennial Challenges webpage. Updated 8 November 2007. NASA. Accessed 19 November 2007. http://www.ip.nasa.gov/cc/index.htm.

6 "X PRIZE Foundation Announces Competitors for Northrop Grumman Lunar Lander Challenge." 20 June 2007. X PRIZE Foundation. Accessed 29 November 2007. http://space.xprize.org/lunar-lander-challenge/assets/FINAL_Wirefly_X_PRIZE_Cup_Teams_Release_6-20-07.pdf.

7 Peter Homer was subsequently contracted by a commercial spacesuit developer, Orbital Outfitters, for work on their spacesuit. See Brian Berger, "Commercial Spacesuit Tailors Hire NASA Contest Winner." 16 November 2007. SPACE.com, Accessed 18 December 2007. http://www.space.com/news/0711116-private-space-suits.html.

8 "NASA's Centennial Challenges to Advance Technologies." 28 August 2007. NASA press release 07-182. Accessed 19 November 2007. http://www.nasa.gov/home/hqnews/2007/aug/HQ_07182_Space_Elevator_Games.html.

9 "Centennial Challenges Descriptions and Resources." Updated 16 May 2007. NASA. Accessed 19 November 2007. http://www.ip.nasa.gov/cc/cc_challenges.htm.

10 "FY 2008 Budget Estimates." NASA President's Fiscal Year 2008 NASA Budget Request. CASP-43. Accessed 19 November 2007. http://www.nasa.gov/about/budget/index.html.

11 Division B – Commerce, Justice, Science and Related Agencies Appropriations Act, 2008." Text of the House Amendments to Senate Amendment to H.R. 2764 – State, Foreign Operations, and Related Programs Appropriations Act, 2008 (Consolidated Appropriations Act, 2008). U.S. House of Representatives Committee on Rules website. Accessed 20 December 2007. http://www.rules.house.gov/110/text/omni/jes/jesdivb.pdf. Page 113.

12 Ray, Justin. "Confident Atlas rocket team ready to launch again". Spaceflight Now, 7 October 2007. http://www.spaceflightnow.com/atlas/av011/071007preview.html. Accessed 6 November 2007.

13 Sea Launch press release. "Sea Launch Concludes Investigation of Launch Failure". 11 June 2007. http://www.sea-launch.com/news_releases/nr_070611.html. Accessed 6 November 2007.

14 Communication with Sea Launch Company, 7 November 2007.

15 Communication with ATK, 2 January 2008.

16 Communication with Space Systems/Loral, 27 November 2007.

17 E'Prime Aerospace Corp. press release. "E'Prime Aerospace Corporation Receives Launch Site Policy Review Approval". 5 November, 2007. http://www.marketwire.com/mw/release.do?id=788716. Accessed 5 November 2007.

18 Communication with Lockheed Martin Michoud Operations, 13 October 2006.

19 Garvey Spacecraft Corporation. "Latest News". http://www.garvspace.com/News.htm. Accessed 5 November 2007.

20 Communication with Garvey Spacecraft Corporation, 7 November 2007.

21 Communication with Microcosm, Inc., 13 November 2007.

22 Schoneman, Scott et al. "Minotaur V Space Launch Vehicle for Small, Cost-Effecive Moon Exploration Missions". 21st Annual AIAA/USU Conference on Small Satellites, paper SSC07-III-2, 2007.

23 AirLaunch LLC press release. "AirLaunch LLC, DARPA, and U.S. Air Force Kickoff Phase 2C". 16 July 2007. http://www.airlaunchllc.com/AirLaunch%20Press%20Release%20Kickoff%20Phase%202C%20071607%20Final.pdf. Accessed 5 November 2007.

24 Communication with AirLaunch LLC, 6 November 2007.

25 Berger, Brian. "Taurus 2 Coming into Focus." *Space News*, September 24, 2007, p. 1.

26 Communication with Zig Aerospace, 17 October 2006.

27 Communication with Sea Launch Company, 7 November 2007.

28 NASA press release. "NASA Awards Upper Stage Engine Contract for Ares Rockets". 16 July 2007. http://www.nasa.gov/home/hqnews/2007/jul/HQ_C07030_J2X_Contract.html. Accessed 5 November 2007.

29 NASA press release. "NASA Selects Ares I Upper Stage Production Contractor". 28 August 2007. http://www.nasa.gov/home/hqnews/2007/aug/HQ_C07040_Ares_1_Upper_Stage_Contract.html. Accessed 5 November 2007.

30 Boeing press release. "Boeing Selected to Build Instrument Unit Avionics for NASA's Ares I Crew Launch Vehicle". 12 December 2007. http://www.boeing.com/news/releases/2007/q4/071212d_nr.html. Accessed 21 December 2007.

31 Communication with Magellan Aerospace Corporation, 9 November 2007.

32 Nammo AS press release. "NAMMO successfully launches Hybrid Test Rocket from Andøya". 8 May 2007. http://www.nammo.com/templates/page.aspx?id=406. Accessed 5 November 2007.

33 UP Aerospace press release. "UP Aerospace, Inc. Successfully Flies Multi-faceted Space Mission." 2 May 2007. http://www.upaerospace.com/DigitalPressKit/UP_Aerospace_Inc_Post-Launch_Press_Release.pdf. Accessed 5 November 2007.

34 Communication with UP Aerospace, 7 November 2007.

35 X PRIZE Foundation. "Acuity Technologies" http://space.xprize.org/lunar-lander-challenge/team_profile_acuity.php. Accessed 20 December 2007.

36 Armadillo Aerospace release. "We failed." 30 October 2007. http://www.armadilloaerospace.com/n.x/Armadillo/Home/News?news_id=350. Accessed 19 November 2007.

37 Communication with Armadillo Aerospace, 20 November 2007.

38 Benson Space Company press release. "Benson Space Improves Design of Its Spaceship". 25 May 2007. http://www.bensonspace.com/press_details.php?id=2. Accessed 15 November 2007.

39 International Space Fellowship. "Interorbital Talk with the Space Fellowship about Their New $1.2 Million Satellite Mission and Joining Forces with Vision One". 27 November 2007. http://spacefellowship.com/News/?p=3806. Accessed 19 December 2007.

40 Interorbital Systems. "Neptune". http://www.interorbital.com/Neptune%20Page_1.htm. Accessed 19 December 2007.

41 Masten Space Systems. "XA-0.1 R.I.P." 17 December 2007. http://masten-space.com/blog/?p=128. Accessed 19 December 2007.

42 X PRIZE Foundation. "Micro-Space". http://space.xprize.org/lunar-lander-challenge/team_profile_micro_space.php. Accessed 20 December 2007.

43 Communication with Micro-Space, 2 January 2008.

44 X PRIZE Foundation. "Paragon Labs". http://space.xprize.org/lunar-lander-challenge/team_profile_paragon_labs.php. Accessed 20 December 2007.

45 PlanetSpace. "Orbital Space Flight". http://www.planet-space.org/lo/osf.htm. Accessed 20 December 2007.

46 Rocketplane Global press release. "Rocketplane Unveils New Suborbital Vehicle Design". 26 October 2007. http://www.rocketplaneglobal.com/press/20071026a.html. Accessed 16 November 2007.

47 Rocketplane Kistler press release. "Rocketplane Kistler Completes NASA-COTS Milestone Ahead of Schedule." 13 February 2007. http://www.rocketplanekistler.com/newsinfo/pressreleases/070213%20-%20PRESS%20RELEASE%20-%20RpK%20Meets%20NASA%20Milestone%20Ahead%20of%20Schedule%200207.pdf. Accessed 17 November 2007.

48 NASA press release. "NASA to Open New Competition for Space Transportation Seed Money". 18 October 2007. http://www.nasa.gov/home/hqnews/2007/oct/HQ_07228_COTS_competition.html. Accessed 17 November 2007.

49 Communication with Virgin Galactic, 17 December 2007.

50 SpaceDev press release. "SpaceDev Signs Space Act Agreement with NASA for Development of Commercial Access to Space." 18 June 2007. http://www.spacedev.com/press_more_info.php?id=205. Accessed 17 November 2007.

51 SpaceDev press release. "SpaceDev and United Launch Alliance to Explore Launching the Dream Chaser Space Vehicle on an Atlas V Launch Vehicle." 10 April 2007. http://www.spacedev.com/press_more_info.php?id=5. Accessed 17 November 2007.

52 Space Access LLC press release. "Space Access Offers Major Expansion of Space Tourism Beginning January 2008". 20 December 2007. http://www.individual.com/story.php?story=75237159. Accessed 20 December 2007.

53 SpaceX. Falcon 1 Launch Vehicle Payload User's Guide, Rev. 6. April 2007. http://www.spacex.com/Falcon%201%20Payload%20Users%20Guide.pdf. Accessed 17 November 2007.

54 SpaceX. "Demo Flight 2 Flight Review Update". 15 June 2007. http://www.spacex.com/F1-DemoFlight2-Flight-Review.pdf. Accessed 17 November 2007.

55 SpaceX. "Falcon 9 Data Sheet" 6 April 2007. http://www.spacex.com/F9%20Data%20Sheet.pdf. Accessed 17 November 2007.

56 Communication with SpaceX, 27 November 2007.

57 SpaceX press release. “SpaceX Signs Deal for First Commercial Geostationary Satellite Launch”. 14 September 2007. http://www.spacex.com/press.php?page=29. Accessed 17 November 2007.

58 SpaceX press release. “SpaceX Breaks Ground at Cape Canaveral’s Space Launch Complex 40”. 1 November 2007. http://www.spacex.com/press.php?page=31. Accessed 17 November 2007.

59 SpeedUp. “News”. http://www.speedupworld.com/news.html. Accessed 20 December 2007.

60 Communication with TGV Rockets, 19 November 2007.

61 t/Space. “Projects: Crew Transfer Vehicle (CXV)”. http://www.transformspace.com/index.cfm?fuseaction=projects.view&workid=CCD3097A-96B6-175C-97F15F270F2B83AA. Accessed 20 December 2007.

62 X PRIZE Foundation. “Unresaonable Rocket”. http://space.xprize.org/lunar-lander-challenge/team_profile_unreasonable_rocket.php. Accessed 20 December 2007.

63 Doupe, Cole, et al. “Fully Reusable Access to Space Technology FAST”. 13 March 2007. http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA467945&Location=U2&doc=GetTRDoc.pdf. Accessed 17 November 2007.

64 Andrews Space press release. “Andrews Space to Work with US Air Force on FAST Program”. 19 March 2007. http://www.andrews-space.com/news.php?subsection=MjMw. Accessed 19 December 2007.

65 Lockheed Martin Michoud Operations. “Lockheed Martin Awarded $14 Million Contract on U.S. Air Force Research Lab FAST Program.” 12 November 2007. http://www.lockheedmartin.com/data/assets/ssc/michoud/PressReleases/LOCKHEEDMARTINAWARDED$14MILLIONCONTRACTONU.S.AIRFORCERESEARCHLABFASTPROGRAM11-12-07.pdf. Accessed 19 December 2007.

66 Northrop Grumman Corporation. “Northrop Grumman to Help Air Force Develop, Demonstrate Technologies for Reusable Launch Vehicles”. 10 December 2007. http://www.irconnect.com/noc/press/pages/news_releases.html?d=132818. Accessed 19 December 2007.

67 Orion Crew Vehicle webpage. Updated 5 November 2007. NASA Constellation Program. Accessed 29 November 2007. http://www.nasa.gov/mission_pages/constellation/orion/index.html.

68 “Constellation Program: Astronaut Safety in a Launch Emergency. The Orion Launch Abort System.” NASA Facts. FS-2007-07-136-LaRC. Accessed 29 November 2007.

69 “Constellation Program: America’s Spacecraft for a New Generation of Explorers. The Orion Crew Exploration Vehicle”. NASA Facts. FS-2006-08-022-JSC. Accessed 29 November 2007.

70 “NASA to Open New Competition for Space Transportation Seed Money.” 18 October 2007. NASA press release 07-228. Accessed 28 November 2007. http://www.nasa.gov/home/hqnews/2007/oct/HQ_07228_COTS_competition.html.

71 Communication with SpaceX, 27 November 2007.

72 See company press releases and information for the new COTS Phase 1 system proposal information:

Constellation Services International: “Constellation Services International and Space Systems Loral Team On NASA COTS Proposal Using a U.S. Version of CSI’s LEO EXPRESS Cargo System.” 11 December 2007. CSI news release. Accessed 19 December 2007. http://www.constellationservices.com/Press_Release_20071211.pdf.

PlanetSpace: “PlanetSpace, Lockheed Martin and ATK team up to bid on NASA COTS.” 21 November 21, 2007. PlanetSpace press release. Accessed 19 December 2007. http://www.planetspace.org/pdf/PressRelease112107.pdf.

SpaceDev: SpaceDev Advanced Systems web page. Accessed 19 December 2007. http://www.spacedev.com/spacedev_advanced_systems.php

SPACEHAB: “SPACEHAB Responds to NASA RFP Seeking Commercial ISS Resupply Means.” 29 November 2007. SPACEHAB press release. Accessed 19 December 2007. http://www.spacehab.com/news/2007/07_11_29.htm.

t/Space: “t/Space enters COTS second round .” November 29, 2007. t/Space News and Media webpage. Accessed 19 December 2007. http://www.transformspace.com/index.cfm?fuseaction=news.view&newsid=8D34F05A-E7F7-11C1-74E37AB2DBDA99CC.

Andrews Space: “Andrews Space Reveals Cargo Vehicle Design Work.” 12 December 2007. Andrews Space press release. Accessed 19 December 2007. http://www.andrews-space.com/news.php?subsection=Mjk3.

73 Lopez, C. Todd Staff Sgt., USAF. “Unmanned vehicle provides reusable test capabilities in space.” 17 November 2006. Air Force Print News online. Accessed 28 November 2007. http://www.af.mil/news/story.asp?storyID=123032226.

74 Shiga, David. “Bigelow Aerospace to offer $760 million for spaceship.” 25 October 2007. New Scientist Space online. Accessed 22 November 2007. http://space.newscientist.com/article/dn12836-bigelow-aerospace-to-offer-760-million-for-spaceship.html.

75 Communication with Bigelow Aerospace, 7 December 2007.

76 Communication with Space Exploration Technologies Corporation, 27 November 2007.

77 Communication with Microcosm, Inc., 27 November 2007.

78 Communication with ATK, Inc., 3 January 2008.

79 ATK press release. “ATK Receives $1.8 Billion Contract to Develop and Support Test Flights for NASA's Ares I Crew Launch Vehicle First Stage” 13 August 2007. http://atk.mediaroom.com/index.php?s=press_releases&item=739. Accessed 4 January 2008.

80 Communication with AirLaunch LLC, 23 November 2007.

81 AirLaunch LLC press release. “AirLaunch LLC, DARPA, and U.S. Air Force Kickoff Phase 2C.” AirLaunchLLC, 16 July 2007. http://www.airlaunchllc.com/News.htm. Accessed 13 November 2007.

82 Communication with Garvey Spacecraft Corporation, 19 November 2007.83 Northrop Grumman press release. “Northrop Grumman Demonstrates New Rocket Engine Design Using Oxygen and Methane Propellants.” Northrop Grumman Corporation, 14 November 2007. http://www.irconnect.com/noc/press/pages/news_releases.html?d=131378. accessed 13 December 2007.

84 NASA Facts Sheet. “The J–2X Engine”. Doc. #FS–2007–08–111–MSFC8–328472, 2007. http://www.nasa.gov/pdf/187393main_j-2x_fact_sheet.pdf. Accessed 27 November 2007.

85 NASA press release. “NASA's J-2X Powerpack Testing Status Report #1” NASA. 19 December 2007. http://www.nasa.gov/centers/marshall/news/news/releases/2007/07-143.html. Accessed 20 December 2007.

86 Pratt & Whitney Rocketdyne press release. “Pratt & Whitney Rocketdyne Awarded $1.2 Billion NASA Contract for J-2X Ares Rocket Engine”. 18 July 2007. http://www.pw.utc.com/vgn-ext-templating/v/index.jsp?vgnextoid=2e35288d1c83c010VgnVCM1000000881000aRCRD&prid=e480c230314d3110VgnVCM100000c45a529f. Accessed 20 November 2007.

87 SpaceX press release. “SpaceX Completes Development of Merlin Regeneratively Cooled Rocket Engine.” SpaceX, 12 November 2007. http://home.businesswire.com/portal/site/google/index.jsp?ndmViewId=news_view&newsId=20071112005019&newsLang=en. Accessed 13 November 2007.

88 SpaceX press release. “SpaceX Completes Development of Merlin Regeneratively Cooled Rocket Engine.” SpaceX, 12 November 2007.

89 SpaceX press release. “SpaceX Completes Development of Merlin Regeneratively Cooled Rocket Engine.” SpaceX, 12 November 2007. http://home.businesswire.com/portal/site/google/index.jsp?ndmViewId=news_view&newsId=20071112005019&newsLang=en. Accessed 13 November 2007.

90 Communication with Space Exploration Technologies, 27 November 2007.

91 SpaceX press release. “SpaceX Completes Development of Merlin Regeneratively Cooled Rocket Engine.” SpaceX, 12 November 2007. http://home.businesswire.com/portal/site/google/index.jsp?ndmViewId=news_view&newsId=20071112005019&newsLang=en. Accessed 13 November 2007.

92 NASA feature. “Methane Blast.” Science@NASA website, 4 May 2007.| http://science.nasa.gov/headlines/y2007/04may_methaneblast.htm. Accessed 13 November 2007.

93 Grossman, Lev. “The Best Inventions of The Year.” *Time Magazine*, 12 November 2007, p. 78.

94 XCOR Aerospace press release. “ATK and XCOR Successfully Complete Test Series

for NASA's 7,500 lbf-thrust LOX/Methane Workhorse Engine”. XCOR Aerospace. 12 December 2007. http://www.xcor.com/press-releases/2007/07-12-12_ATK_and_XCOR_complete_LOX_methane_testing.html. Aaccessed 18 December 2007.

95 Boyle, Alan. “Rocket Racer Revealed”. Cosmic Log. 7 November 2007. http://cosmiclog.msnbc.msn.com/archive/2007/11/07/454487.aspx. Accessed 25 November 2007.

96 Orion Propulsion Inc. press release. “Latest News - October 2006.” Orion Propulsion Inc., October 2006. http://orionpropulsion.com/latestnews.php. Accessed 11 October 2006.

97 Orion Proulsion Inc. press release. “Latest News: Innovative Thruster Module Successfully Tested” Orion Propulsion Inc. 7 December 2007. http://www.orion-propulsion.com/. Accessed 20 December 2007.

98 Communication with Space Exploration Technologies, 27 November 2007.

99 Orbital press release. “Orbital To Provide Launch Abort System For NASA’s Orion Crew Exploration Vehicle” 1 September 2006. http://www.orbital.com/newsinfo/release.asp?prid=570. Accessed 26 November 2007.

100 NASA press release. “NASA to Break Ground for Orion Test Pad at White Sands, N.M.” 8 November 2007. http://www.nasa.gov/home/hqnews/2007/nov/HQ_M07158_ESMD_White_Sands_Groundbreaking.html. Accessed 4 January 2008.

101 Orbital fact sheet. “Orion Crew Exploration Vehicle Launch Abort System (LAS)” Orbital Sciences Corporation. 2006. http://www.orbital.com/NewsInfo/Publications/LAS_Fact.pdf#search="launch abort system. Accessed 26 November 2007.

102 Pratt & Whitney Rocketdyne press release. “Pratt & Whitney Rocketdyne’s Revolutionary Scramjet Engine Successfully Powers First X-51A Simulated Flight” Pratt & Whitney Rocketdyne. 30 April 2007. http://www.pw.utc.com/vgn-ext-templating/v/index.jsp?vgnextoid=2e35288d1c83c010VgnVCM1000000881000aRCRD&prid=0c8381dc89e22110VgnVCM100000c45a529f____. Accessed 13 December 2007.

103 Andrews Space Inc. press release. “Andrews Awarded DARPA/AFRL Contract to Demonstrate In-Flight Propellant Generation For Advanced Space Transportation.” Andrews Space, Inc., 27 March 2006. http://www.andrews-space.com/news.php?subsection=MjA1. Accessed 16 October 2006.

104 Communication with Andrews Space, Inc. 21 December 2007.

105 Air Launch LLC press release. “Operational C-17A Used to Break Another Record with Air Launch in DARPA/Air Force Falcon Small Launch Vehicle Program.” Air Launch LLC, 27 July 2006. www.californiaspaceauthority.org/images/pdfs/pr060801-1.pdf. Accessed 10 October 2006.

106 Communication with AirLaunch LLC., 23 November 2007.

107 Andrews Space press release. “Andrews Space Develops Advanced Thermal Protection Materials for Reentry Applications”. Andrews Space. 20 December 2007. http://www.andrews-space.com/news.php?subsection=Mjk4. Accessed 20 December 2007.

108 Boeing press release. “Boeing Completes Prototype Heat Shield for NASA Orion Spacecraft” Boeing, 13 November 2007. http://www.boeing.com/ids/news/2007/q4/071113a_nr.html. Accessed 20 November 2007.

109 NASA press release. “Success for Second Ares Main Parachute Test” 15 November 2007. http://www.nasa.gov/mission_pages/constellation/multimedia/photos07-126_2.html. Accessed 20 December 2007.

110 Alliant Techsystems press release. “World’s largest Rocket Stage Recovery Parachute Test is Successful” 2 October 2007. http://atk.mediaroom.com/index.php?s=press_releases&item=752. Accessed 14 November 2007.

111 “Final Environmental Assessment for the Proposed Blue Origin West Texas Launch Site.” FAA/AST, August 2006. http://www.faa.gov/about/office_org/headquarters_offices/ast/media/20060829_Blue_Origin_EA_Signed.pdf. Accessed 08 November 2006.

112 “AST Issues First Experimental Permit for a Reusable Suborbital Rocket to Blue Origin.” FAA/AST, 25 September 2006. http://ast.faa.gov/Exper_Permit_Blue_Origin.htm. Accessed 8 November 2006

.113 Communication with California Spaceport, 21 November 2007.

114 Ibid.

115 Communication with Space Florida, 26 November 2007.

116 Ibid.

117 Ibid.

118 Ibid.

119 Ibid.

120 Ibid.

121 Communication with Mid-Atlantic Regional Spaceport, 8 November 2007.

122 Ibid.

123 Ibid.

124 Ibid.

125 Communication with Mojave Airport, 17 October 2006.

126 David, Leonard. “XCOR Rocket Plane Soars into Record Book.” SPACE.com, 3 December 2005. http://www.space.com/missionlaunches/051203_xcor_flight.html. Accessed 28 December 2005.

127 Boyle, Alan. “Regulators OK Oklahoma Spaceport.” MSNBC, 13 June 2006. http://www.msnbc.msn.com/id/13304491. Accessed 2 November 2006.

128 Ibid.

129 Communication with Oklahoma Space Industry Development Authority, 26 October 2006.

130 Ibid.

131 Communication with Cape Canaveral Air Force Station, 30 September 2005.

132 Department of the Air Force, Edwards Air Force Base. “Memorandum for Government Agencies, Public Officials, Libraries, Public Groups, and Interested Individuals.” U.S. Air Force, December 2002. http://www.ealev.com. Accessed 7 November 2006.

133 NASA Press Release (58-06). “NASA Requests Proposals for Exploration Park Developer.” NASA, 1 September 2006. http://www.nasa.gov/centers/kennedy/news/releases/2006/release-20060901.html. Accessed 3 November 2006.

134 NASA Press Release (04-06). “GlobalFlyer Aircraft Arrival Set for This Week.” NASA, 9 January 2006. http://www.nasa.gov/centers/kennedy/news/releases/2006/release-20060109.html. Accessed 3 November 2006.

135 NASA Press Release (06-132). “NASA and ZERO-G Agree on Regular Shuttle Runway Use.” NASA, 4 April 2006. http://www.nasa.gov/centers/kennedy/news/releases/2006/release-20060404.html. Accessed 3 November 2006.

136 NASA RFI-SLF-1. "Request For Information Supporting an Environmental Assessment of Commercial and other uses of the Shuttle Landing Facility." NASA, 29 September 2006. http://procurement.nasa.gov/cgi-bin/eps/sol.cgi?acqid=122399#Other%2001, Accessed 3 November 2006.

137 "KSC Hosts Private Jet's Suborbital Pathfinder Flights." 12 April 2007. http://www.vmaxmarketing.com/news/nasa1.htm. Accessed 3 January 2008.

138 Communication with Reagan Test Site, 6 November 2007.

139 Communication with Reagan Test Site, 20 October 2006.

140 Communication with Vandenberg Air Force Base, 7 October 2005.

141 Communication with NASA Wallops Flight Facility, 11 October 2005.

142 Communication with Wallops Flight Facility, 15 November 2007.

143 Ibid.

144 Communication with White Sands Missile Range, 6 October 2005.

145 Communication with White Sands Missile Range, 1 December 2007.

146 Communication with Cecil Field Spaceport, 20 November 2007.

147 Ibid.

148 Communication with Chugwater Spaceport, 14 December 2007.

149 Communication with Aerospace Development Center, 23 September 2004.

150 Reid, T.R. "N.M. Plans Launchpad for Space Tourism." *The Washington Post*, 15 December 2005. http://www.washingtonpost.com/wp-dyn/content/article/2005/12/14/AR2005121402340.html. Accessed 3 November 2006.

151 Communication with Office for Space Commercialization, New Mexico Economic Development Department, 21 November 2007.

152 Ibid.

153 "Pact Clears the Way for New Spaceport Site. New Mexico Signs Agreement on Access to 15,000 acres of State Trust Land." Associated Press, 11 January 2006. http://msnbc.msn.com/id/10807954. Accessed 3 November 2006.

154 David, Leonard. "New Mexico Inks Spaceport Funding Package." SPACE.com, 2 March 2006. http://www.space.com/news/060302_newmexico_update.html. Accessed 3 November 2006.

155 Communication with Office for Space Commercialization, New Mexico Economic Development Department, 21 November 2007.

156 Ibid.

157 Communication with Space Explorers, 21 November 2007.

158 2005 Senate Bill 352. Wisconsin State Legislature, 28 September 2005. http://www.legis.state.wi.us/2005/data/SB-352.pdf. Accessed 21 November 2006.

159 Egan, Dan. "With All Systems Go, Sheboygan Shoots for the Moon with Spaceport." The Milwaukee Journal Sentinel, 12 May 2006. http://www.findarticles.com/p/articles/mi_qn4196/is_20060512/ai_n16370976/print. Accessed 7 November 2006.

160 Communication with Space Explorers, 21 November 2007.

161 Communication with Port of Moses Lake, 6 October 2006.

162 Communication with Spaceport Washington, 27 September 2005.

163 Communication with Port of Moses Lake, 6 October 2006.

164 Pecos County Aerospace Development Center Technical Description. Pecos County West Texas "Westex" Spaceport Development Corporation, 2006. http://www.aerospacetexas.com/uguide/index.html. Accessed 21 November 2006.

165 Communication with Pecos County West Texas "Westex" Spaceport Development Corporation, 10 October 2005.

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