Federal Aviation Administration

# 2011 U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports

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Cover art courtesy Phil Smith.

## About the Office of Commercial Space Transportation

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

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# INTRODUCTION

On June 28, 2010, the United States released a new National Space Policy that commits the United States to a robust and competitive industrial base. The policy states that "the U.S. Government will use commercial space products and services in fulfilling government needs... [and will] seek partnerships with the private sector to enable commercial spaceflight capabilities for the transportation of crew and cargo to and from the International Space Station (ISS)." With the impetus of the new policy, 2010 was an exceptional year for U.S. commercial space transportation development.

Established providers of commercial launch services continued to deliver satellites to orbit, while entrepreneurial ventures made significant strides in developing new expendable and reusable launch vehicles. This year also saw new developments in commercial space transportation technologies, including advancements in rocket propulsion, emergency detection for crew transportation, and life support systems. In 2010, spaceports across the U.S. continued infrastructure improvements, such as the new runway for Virgin Galactic's suborbital flights at New Mexico's Spaceport America.

Firms based around personal spaceflight came closer to meeting their goal of beginning operations in 2011. Scaled Composites successfully performed captive carry and glide flights of SpaceShipTwo. Companies, such as Paragon Space Development Corporation, Aerojet, Pratt & Whitney Rocketdyne, and Sierra Nevada Corporation, made significant strides in innovative technologies to support new vehicles. Also related to personal space flight, in October, the President signed into law the National Aeronautics and Space Administration (NASA) Authorization Act for fiscal year 2011 through 2013. This act called for NASA to foster development of commercial crew and cargo for low Earth orbit.

The Federal Aviation Administration's Office of Commercial Space Transportation (FAA/AST) took a number of historical actions in 2010. It established the Air Transportation Center of Excellence for Commercial Space Transportation to encourage a partnership among academia, industry, and government to address challenges for commercial space transportation. In April, the Pennsylvania-based National AeroSpace Training and Research (NASTAR) Center received the first FAA/AST safety approval for a commercial Spaceflight Training System. In October, FAA/AST issued $500,000 in grants to four spaceports, under its new Space Transportation Infrastructure Matching Grant Program. FAA/AST also issued its first reentry license to Space Exploration Technologies (SpaceX) for its Dragon spacecraft in November.

This report reviews the developments and concepts that defined U.S. commercial space transportation in 2010. It showcases current and planned U.S. commercial space activities and highlights developments in 2010. It also examines expendable launch vehicles, reusable launch vehicles, reentry vehicles and in-space technologies, enabling technologies for propulsion and other vehicle components, the evolving array of U.S. spaceports, current space prizes and competitions, and new developments in commercial human spaceflight training. The U.S. commercial space transportation industry has a $208 billion impact on the U.S. economy[1] and supports over a million jobs. The commercial space industry remains dynamic.

This report relies both on public sources addressing development and concept activities within the last year and also on direct contacts with the companies profiled in this study. FAA is grateful for the support and cooperation of the companies who contributed to this report. Their support allowed for a more comprehensive and accurate view of advancements in the U.S. commercial space transportation industry.

The 2010 U.S. Commercial Space Transportation Developments and Concepts report is a companion document for FAA/AST's other publications, including *The Economic Impact of Commercial Space Transportation on the U.S. Economy in 2009*, the *2010 U.S. Commercial Space Transportation Year in Review*, and the forthcoming annual launch forecast to be published in May 2011.

# SIGNIFICANT EVENTS IN 2010

2010 was an eventful year for U.S. commercial space transportation. FAA/AST issued its first safety approval for a commercial Spaceflight Training System to NASTAR and a spaceport license for Florida's Cecil Field Spaceport. AST announced its Commercial Space Transportation Infrastructure Matching Grant Program and established the first FAA Air Transportation Center of Excellence for Commercial Space Transportation. Also during the year, NASA selected the first round of winners for the Commercial Crew Development (CCDev) initiative, Scaled Composites started test flights of its SpaceShipTwo suborbital crewed vehicle, and SpaceX's inaugural Falcon 9 launch was a success.

Significant events in U.S. commercial space transportation for 2010 are grouped by the chapters of this report. Only events related to U.S. commercial launch contracts, U.S. commercially available space vehicles, and FAA/AST-licensed spaceports are included. Significant events related to national space policy that impact U.S. commercial space transportation and significant FAA/AST activities are also highlighted.

## Expendable Launch Vehicles

### SpaceX and Spacecom Sign Agreement for Falcon 9 Mission

On January 7, SpaceX and Space Communication Ltd. (Spacecom) signed an agreement to launch a communication satellite aboard a SpaceX Falcon 9 rocket. The Falcon 9 will place the satellite AMOS-6 into geosynchronous Earth orbit by December 2012.[2]

### SpaceX and SS/L Sign Agreement

On March 15, SpaceX and Space Systems/Loral (SS/L) signed an agreement to launch an SS/L-manufactured satellite aboard a Falcon 9 to geosynchronous transfer orbit (GTO) by 2012.[3]

### SpaceX's Inaugural Launch of Falcon 9 Reaches Earth Orbit

On June 4, SpaceX's Falcon 9 rocket reached Earth orbit on its first launch attempt from Cape Canaveral Air Force Station (CCAFS). The vehicle, which carried a Dragon mockup, entered a circular orbit around Earth at an altitude of 249 kilometers (155 miles).[4]

### SpaceX and Taiwan's NSPO Sign Contract

On June 14, SpaceX and the National Space Organization (NSPO), the civilian space agency of the Republic of China (Taiwan), announced a contract to launch the Earth observation satellite Formosat-5 on a Falcon 1 launch vehicle.[5]

### SpaceX and Iridium Sign Contract

On June 16, SpaceX and Iridium Communications Inc. signed a contract to launch Iridium's NEXT satellite constellation on SpaceX's Falcon 9 vehicles. The Iridium launches are set to launch from Vandenberg Air Force Base between 2015 and 2017. The contract is valued at $492 million.[6]

### Sea Launch Signs Launch Agreement with AsiaSat

On July 12, Sea Launch signed a contract with Asia Satellite Telecommunications Company Limited (AsiaSat) to provide launch services for a payload going to GTO. Sea Launch's Zenit-3SL will launch the payload from Sea Launch's equatorial launch site in the Pacific Ocean, between 2012 and 2014.[7]

### Sea Launch Signs Launch Agreement with EchoStar

On July 22, Sea Launch Company signed an agreement with EchoStar Satellite Services LLC to provide EchoStar with up to three satellite launches on Zenit 3SL vehicles. The launches will take place at Sea Launch's equatorial launch site in the Pacific Ocean. No timeframe has been announced for the launches.[8]

### GeoEye Selects LMCLS to Launch GeoEye-2

On September 7, GeoEye Inc. signed a contract with Lockheed Martin Commercial Launch Services (LMCLS) to launch the GeoEye-2 Earth-imaging satellite aboard an Atlas V vehicle in 2012.[9]

### Sea Launch Emerges from Bankruptcy

On October 27, Sea Launch announced it has successfully completed its Chapter 11 reorganization process. Energia Overseas Limited acquired a majority ownership of the reorganized company, now named Sea Launch AG.[10]

### SpaceX Successfully Launches Falcon 9 Under COTS

On December 8, SpaceX conducted a successful launch of Falcon 9, the first test under a Commercial Orbital Transportation Services (COTS) Space Act Agreement with NASA. The vehicle carried a fully functional Dragon cargo spacecraft, which was tested on orbit for about five hours before it returned successfully later that day as scheduled.

## Reusable Launch Vehicles

### VSS Enterprise Completes First Captive Carry Flight

On March 3, Virgin Galactic's VSS Enterprise conducted its first captive carry flight attached to the WhiteKnightTwo aircraft from Mojave Air and Space Port. Virgin Galactic had to demonstrate the captive carry capability before it could begin flight-testing for its suborbital tourism program.[11]

### Space Adventures and Armadillo Announce Partnership

On April 29, Space Adventures Ltd. and Armadillo Aerospace announced a formal partnership, in which Space Adventures will market flights on Armadillo's flight systems.[12]

### Masten Demonstrates In-Air Re-Lighting of Engine

On May 26, Masten Space Systems used its vertical take-off, vertical landing vehicle Xombie to demonstrate the capability to re-light the rocket engine in midair. This was the first successful demonstration of this capability in history. The flight took place at the Mojave Air and Space Port.[13]

### VSS Enterprise Makes First Crewed Flight

On July 15, Virgin Galactic's VSS Enterprise made its first crewed flight, using the captive carry configuration with the WhiteKnightTwo. The crew evaluated the Enterprise's systems from end to end and accomplished all objectives for the flight.[14]

### FAA Establishes Air Transportation Center of Excellence for Commercial Space Transportation

On August 18, U.S. Transportation Secretary Ray LaHood announced FAA selected New Mexico State University to lead a new Air Transportation Center of Excellence for Commercial Space Transportation. The FAA center is a partnership of academia, industry, and government addressing current and future challenges for commercial space transportation.[15] Other involved universities are the New Mexico Institute of Mining and Technology, Florida Institute of Technology, Florida Center for Advanced Aero-Propulsion, Stanford University, University of Colorado at Boulder, and the University of Texas Medical Branch.[16]

### NASA Selects Two Firms for Commercial Experimental Space Vehicle Test Flights

On August 30, NASA's Commercial Reusable Suborbital Research Program announced that it awarded two contracts worth approximately $475,000 to Armadillo and Masten for experimental space vehicle test flights. Under the terms of the contract, Masten will conduct four flights of test payloads to altitudes of up to 29 kilometers (18 miles) with the Xaero vehicle. Armadillo will conduct two flights of its Super-Mod vehicle to altitudes of up to 40 kilometers (25 miles).[17]

### XCOR Completes Wind Tunnel Tests on Lynx

On September 20, XCOR Aerospace Inc. announced the completion of wind tunnel tests at NASA's Marshall Space Flight Center. The tests validated the aerodynamic shape of the spacecraft and assured the craft's ability to withstand the unique flight conditions it will encounter.[18]

### SXC Signs Agreement with XCOR

On October 4, Space Experience Curaçao (SXC) signed a memorandum of understanding with XCOR for the lease of XCOR's Lynx spacecraft to SXC. Under the agreement, SXC will market Lynx flights from the Curaçao spaceport in the Netherlands Antilles. XCOR will own and operate the vehicle.[19]

### VSS Enterprise Completes First Crewed Glide Flight

On October 10, Virgin Galactic's VSS Enterprise completed its first free glide flight from over 13,106 meters (43,000 feet). Two pilots crewed the craft and landed it safely at the Mojave Air and Space Port.[20]

## Reentry Vehicles and In-Space Technologies

### NASA Selects Five Companies to Receive Funding for CCDev

On February 1, NASA awarded Sierra Nevada Corporation, Boeing, United Launch Alliance, Blue Origin, and Paragon Space Development Corp. seed funding totaling $50 million to aid in developing each company's respective commercial crew transportation systems. These awards were made under NASA's CCDev program, with funding distributed in accordance with Space Act Agreements.[21]

### SpaceX Activates Communication System Aboard ISS

On March 29, SpaceX successfully activated its Dragon communication hardware aboard the ISS. The hardware will allow ISS crewmembers to monitor and control SpaceX's Dragon spacecraft during cargo delivery. The Dragon was one of two systems contracted to demonstrate delivery of cargo to the ISS under NASA's COTS contract.[22]

### SpaceX Dragon Spacecraft Completes High Altitude Drop Test

On August 20, SpaceX's Dragon capsule successfully passed a high altitude drop test to validate the capsule's parachute deployment systems.[23]

### Boeing and Space Adventures Announce Partnership

On September 15, Boeing and Space Adventures announced a memorandum of agreement to partner on marketing Boeing's commercial crew vehicles to low Earth orbit (LEO). Space Adventures will exclusively market Boeing's CST-100 vehicle, which Boeing expects will begin flying by 2015.[24]

### NASA Seeks Proposals for CCDev Round Two

On October 15, NASA announced that it was seeking proposals from the U.S. commercial space industry to further develop commercial crew systems. NASA is considering approximately $200 million for the Space Act Agreement solicitation, but funding depends upon 2011 fiscal year appropriations from Congress. NASA expects to announce multiple awards through March 2011.[25]

### Bigelow Receives Expressions of Interest from Six Countries

On October 22, Bigelow Aerospace signed agreements with national space agencies, companies, and governmental entities in the Netherlands, Sweden, Singapore, Japan, the United Kingdom, and New South Wales, Australia. These agreements are formal expressions of support to lease Bigelow modules once in orbit; however, these agreements did not involve financial terms.[26]

### Bigelow Conducts Life Support Systems Testing

On October 22, Bigelow Aerospace announced that it has begun testing environmental control and life support systems with volunteer crews. The company is testing systems that will be used on its inflatable in-space habitat Sundancer.[27]

### NASA Releases Commercial Crew Certification Requirements

December 9, 2010, NASA released its *Commercial Crew Transportation System Certification Requirements for NASA Low Earth Orbit Missions*. This document defines the requirements, standards, and certification package that will be used to certify a commercial crew transport system to carry NASA crewmembers on LEO missions, in particular the ISS. This certification only applies to NASA missions.[28]

## Spaceports

### Space Florida Breaks Ground on Exploration Park

On June 25, Space Florida broke ground on Exploration Park, which will feature eight buildings totaling 315,000 square feet, just outside NASA's Kennedy Space Center (KSC) security gates. The park will house a multitude of entities that seek to use KSC, including commercial users.[29]

### Orbital Adds Infrastructure for Taurus II Launches to MARS

On July 7, Mid-Atlantic Regional Spaceport (MARS) announced that Orbital would add a new 80,000-gallon liquid oxygen tank at its Taurus II launch site. In June, Orbital erected a 91-meter (300-foot) water tower for its acoustic suppression system.[30]

### Space Florida Receives FAA License for LC-46

On July 9, the FAA issued Space Florida a license to conduct commercial space launches at Launch Complex-46 (LC-46) on the property of CCAFS.[31]

### Spaceport America Dedicates Runway

On October 22, Spaceport America in Upham, New Mexico, completed and dedicated its nearly three-kilometer (two-mile) runway that will be used for horizontal take off and landing by commercial space entities.[32]

### The Spaceship Company Breaks Ground on Hangar

On November 9, the company founded by Virgin Galactic and Scaled Composites broke ground at Spaceport America in New Mexico for its 6,317 square meter (68,000 square foot) hangar. The hangar will house the company's final assembly, integration, and testing of its vehicles.[33]

## Enabling Technologies

### Orbital and Aerojet Complete Main Engine Lifetime Testing for Taurus II

On March 15, Orbital Sciences Corporation (Orbital), Aerojet, and their Russian partner, United Engine Corporation/SNTK, announced the completion of a series of NK-33 engine tests in Samara, Russia. The NK-33 is the engine for the first stage of Orbital's Taurus II launch vehicle, which is currently in development.[34]

### XCOR and Masten Announce Partnership for Lander Development

On May 25, XCOR and Masten announced their intention to partner on the anticipated NASA unmanned lander projects.[35]

### XCOR and ULA Announce Successful Piston Pump Tests

On June 8, United Launch Alliance (ULA) and XCOR announced the first successful demonstration of the jointly developed, long-life, high-performance piston pump with liquid hydrogen. XCOR first developed the pump to use liquid oxygen and liquid nitrogen. ULA intends to test the technology for a range of applications, including pump-fed liquid hydrogen rocket engines for upper-stages of launch vehicles.[36]

## Prizes and Competitions

### Six Google Lunar X PRIZE Competitors Awarded NASA Contracts

In October, NASA awarded contracts to six Google Lunar X PRIZE teams as part of the Innovative Lunar Demonstrations Data program. The teams will provide NASA with data on technical component demonstrations for lunar missions. Each contract is a firm-fixed price, indefinite-delivery/indefinite-quantity contract, and the total value of all awarded contracts is up to $30.1 million, over a period of up to five years. On December 20, NASA issued delivery orders, each worth $500,000, to three of these teams.[37]

## Human Spaceflight Training

### New Mexico Passes Commercial Space Flight Informed Consent Law

On March 1, New Mexico Governor Bill Richardson signed the Space Flight Informed Consent Act. This act requires commercial spaceflight companies to fully inform their passengers of the risks of space travel. All passengers flying from New Mexico must sign a waiver acknowledging that they understand and accept the inherent risks of spaceflight activities.[38]

### NASTAR Receives First FAA Safety Approval for Training

On April 22, the NASTAR Center, a subsidiary of Environmental Tectonics Corporation, received the first FAA/AST safety approval for a commercial Spaceflight Training System, the company's STS-400 simulator. NASTAR will use the simulator to train prospective space launch operators. Their training will satisfy the crew qualification and training requirements outlined in the Code of Federal Regulations (14 CFR Section 460.5).[39]

## Regulatory and Legislative Developments

### Administration Proposes NASA Budget for FY 2011

On February 1, the Administration announced its fiscal year 2011 proposed budget for NASA. The budget proposal increased the agency's budget by $6 billion over the next five years. The proposal also featured dramatic shifts in the human spaceflight program, including cancelling the Constellation Program. The budget proposal used the savings from the cancellation to fund a new technology research program and a commercial space transportation program to ferry astronauts to and from the ISS.[40]

### FAA Announces Commercial Space Transportation Infrastructure Matching Grant Program

On May 4, FAA/AST published a notice in the Federal Register announcing the inauguration of the $500,000 Space Transportation Infrastructure Matching Grant Program.[41]

### Administration Releases National Space Policy

On June 28, the President announced the National Space Policy of the United States. The policy emphasizes the need to facilitate and grow the U.S. commercial space sector to support U.S. needs and compete globally. It provides a definition of commercial space.[42]

### FAA Awards First Commercial Space Transportation Infrastructure Matching Grant

On October 2, FAA/AST announced awardees for the Commercial Space Transportation Infrastructure Matching Grant Program. The New Mexico Spaceport Authority received $43,000 to provide an automated weather observing system. The East Kern Airport District in Mojave, California received $125,000 for an emergency response vehicle. The Jacksonville Airport Authority in Florida received $104,805 to develop a Spaceport Master Plan for Cecil Field Spaceport. The Alaska Aerospace Corporation received $227,195 for a rocket motor storage facility.[43]

### President Signs NASA Authorization Act

On October 11, the President signed the NASA Authorization Act of 2010 into law. The act authorizes $19 billion for NASA in fiscal year 2011. The law allocates funding for an additional shuttle flight, accelerates NASA's development of a heavy-lift vehicle, and funds development of commercial spaceflight systems to ferry U.S. astronauts to LEO.[44]

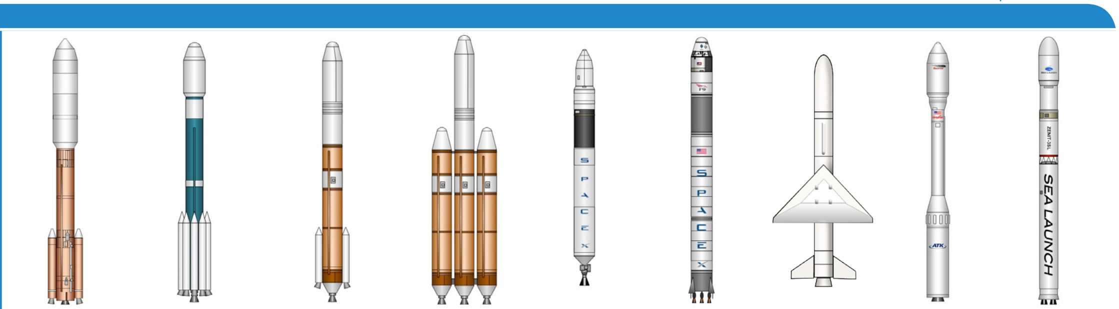
# EXPENDABLE LAUNCH VEHICLES

Expendable Launch Vehicles (ELVs) are single-use rockets designed to traverse the atmosphere on trajectories that transport a payload. The payload may be transported on a ballistic trajectory (suborbital) or may be placed into orbit around the planet (orbital). ELVs, which share a development history with missile technology, have been in use since the 1950s.

The following survey of U.S. ELVs licensed by the FAA is in three sections. The first section reviews 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. The third reviews commercially available suborbital sounding rockets.

## Current Expendable Launch Vehicle Systems

Table 1 lists the ELV systems currently licensed by the FAA. This list does not include the following government-only orbital vehicle systems, which do not require an FAA license: the Space Transportation System (or Space Shuttle), the Ares system currently in development, and Orbital Sciences Corporation's (Orbital) Minotaurs I, IV, and V.




| Vehicle | Atlas V | Delta II | Delta IV | Delta IVH | Falcon 1 | Falcon 9 | Pegasus XL | Taurus | Zenit 3SL |
|---|---|---|---|---|---|---|---|---|---|
| Company | LMCLS/ULA | BLS/ULA | BLS/ULA | BLS/ULA | SpaceX | SpaceX | Orbital | Orbital | Sea Launch |
| First Launch | 2002 | 1990 | 2002 | 2004 | 2006 | 2010 | 1990 | 1994 | 1999 |
| Stages | 2 | 3 | 2 | 2 | 2 | 2 | 3-4 | 3 | 2 |
| Capacity to LEO kg(lb) | 12,500 (27,558) to 20,520 (45,238) | 6,097 (13,443) | 9,390 (20,702) to 13,360 (29,440) | 22,977 (50,646) | 420 (924) | 10,450 (23,050) | 440 (970) | 1,458 (3,214) | N/A |
| Capacity to SSO kg(lb) | 7,095 (15,642) to 14,096 (31,076) | 3,123 (6,886) | 7,510 (16,550) to 11,300 (24,920) | 22,560 (49,740) | 420 (924) | 8,560 (18,870) | 190 (420) | 1054 (2,324) | N/A |
| Capacity to GTO kg(lb) | 4,750 (10,450) to 8,900 (19,580) | 900 (1,980) to 2,171 (4,787) | 4,541 (10,012) to 7,020 (15,470) | 13,399 (29,540) | N/A | 4,540 (10,000) | N/A | 430 (950) | 6,180 (13,624) |
| Launch Sites | CCAFS VAFB | CCAFS VAFB | CCAFS VAFB | CCAFS VAFB | Kwajalein CCAFS | CCAFS Kwajalein | Various (air-launched) | VAFB | Pacific Ocean |

Table 1: Commercially available ELVs in the United States (vehicle images not to scale).

### Atlas V – Lockheed Martin Commercial Launch Services/United Launch Alliance

Atlas V

The Atlas V launch vehicle is an intermediate- to heavy-lift vehicle, depending on configuration, and is manufactured by United Launch Alliance (ULA), a joint venture between Lockheed Martin and Boeing. ULA also markets the Atlas V to U.S. Government customers. Lockheed Martin Commercial Launch Services (LMCLS) brokers commercial Atlas V launches. Originally, Lockheed Martin developed the Atlas V for the Evolved Expendable Launch Vehicle Program (EELV), which also facilitated the development of Boeing's Delta IV vehicle system. Variants of the Atlas V have successfully launched 23 missions to orbit: 15 U.S. government missions and eight commercial missions.

The Atlas V has two active vehicle variants: the 400 and 500 series. Both series use a Common Core Booster (CCB) first stage and an upper-stage Centaur vehicle. The RD-180 engine, a product of RD AMROSS, powers the CCB. The upper-stage Centaur uses the RL10 engine from Pratt and Whitney Rocketdyne. Up to five solid rocket boosters can be added to the 400 and 500 series configurations. A proposed heavy variant of the Atlas V could feature a flight configuration of three CCBs. The Atlas V is capable of launching out of Cape Canaveral Air Force Station (CCAFS) in Florida and Vandenberg Air Force Base (VAFB) in California.[1]

The 400 series features a payload fairing diameter of 4.2 meters (13.1 feet) and can launch up to 15,130 kilograms (33,650 pounds) to low Earth orbit (LEO) and up to 7,700 kilograms (16,970 pounds) to geosynchronous transfer orbit (GTO). The 500 series features a payload fairing diameter of 5.4 meters (17.6 feet) and can launch up to 18,510 kilograms (40,800 pounds) to LEO and 8,900 kilograms (19,260 pounds) to GTO.[2] Sierra Nevada Corporation's Dream Chaser, profiled later in this report, is a crewed space plane designed to launch aboard an Atlas V.

In 2010, the Atlas V had four successful launches with all four missions reaching their prescribed orbit, including NASA's Solar Observatory mission and the maiden flight of the U.S. Air Force's X-37B Orbital Test Vehicle built by Boeing. Seven Atlas V flights are expected in 2011.

### Delta II – Boeing Launch Services/United Launch Alliance

ULA designed, built, and operates the Delta II launch vehicle, an intermediate-class vehicle. There are many variants of the Delta II, depending on booster, stage, and fairing configuration. Along with the Delta IV and Atlas V, ULA brokers Delta II launch services to the U.S. Government. Boeing Launch Services (BLS) markets the Delta II to commercial clients.


Delta II

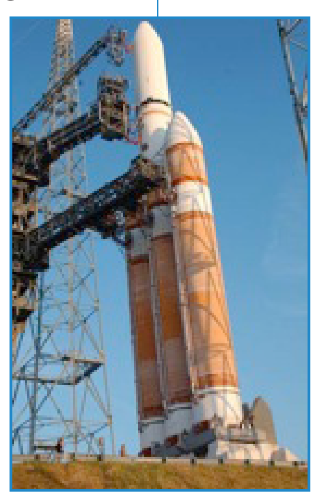
The Delta II is a three-stage, liquid-fueled vehicle. A single RS-27 engine fed with liquid oxygen (LOX) and rocket grade kerosene powers the first stage, which can be supplemented by up to nine solid rocket boosters. A hypergolic (combustion occurs when the oxidizer and fuel mix, without the aid of a heat source) Aerojet AJ10-118K engine powers the second stage, which also houses the avionics. Finally, the vehicle can use an optional solid motor kick stage, by Alliant Techsystems (ATK) Thiokol, for missions to points beyond LEO. Three different payload fairings are available depending on payload dimensions.

The Delta II vehicle can directly trace its lineage to the Air Force's Thor missile of the 1960s. It was originally developed by McDonnell Douglas, and later Boeing acquired it. The vehicle has been a workhorse for government and commercial clients since 1989, having successfully launched 143 missions since 1989. ULA is no longer producing the Delta II; however, a total of eight Delta II vehicles remain. Three of these are under contract with NASA and have assigned payloads. Payloads for the other five are being negotiated.[3] The Delta II performed one flight in 2010, an FAA-licensed mission from VAFB carrying the final Cosmo-Skymed remote sensing satellite for Italy. Three Delta II flights are expected in 2011.

### Delta IV – Boeing Launch Services/United Launch Alliance

The Delta IV is an intermediate- to heavy-lift vehicle, depending on the configuration, and was originally developed for the EELV Program. Along with the Delta II and Atlas V, ULA brokers Delta IV launch services to the U.S. Government, while BLS markets the vehicle to commercial clients. Since 2006, ULA has constructed the Delta IV. It has successfully launched 14 missions to orbit: 13 U.S. government missions and one commercial mission.

The Delta IV is available in four variants: the Delta IV Medium, two versions of the Delta IV Medium-Plus, and the Delta IV Heavy (pictured). All three variants use a Common Booster Core (CBC) first stage and an upper-stage vehicle. The RS-68 engine, a product of Pratt and Whitney Rocketdyne, powers the CBC. The upper



Delta IV

stage uses the RL10B-2, also a product of Pratt and Whitney Rocketdyne. Up to four solid rocket booster motors can be added to the Medium-Plus variant. The Delta IV Heavy features three CBCs flown together in tandem. The Delta IV is capable of launching out of CCAFS and VAFB.[4] Table 2 provides capacity information for the five variants of the Delta IV.

| | Delta IV Medium | Delta IV Medium-Plus (4,2) | Delta IV Medium-Plus (5,2) | Delta IV Medium-Plus (5,4) | Delta IV Heavy |
|---|---|---|---|---|---|
| LEO kg (lb) | 9,150 kilograms (20,170 pounds) | 12,240 kilograms (29,980 pounds) | 10,640 kilograms (23,457 pounds) | 13,360 kilograms (29,440 pounds) | 22,560 kilograms (49,740 pounds) |
| GTO kg (lb) | 4,300 kilograms (9,480 pounds) | 6,030 kilograms (13,290 pounds) | 4,640 kilograms (10,230 pounds) | 7,020 kilograms (15,470 pounds) | 12,980 kilograms (28,620 pounds) |

Table 2: Capacities for Delta IV variants.

In November 2010, Lockheed Martin began negotiations with ULA to purchase a Delta IV Heavy vehicle to launch a test version of Lockheed Martin's Orion capsule in 2013. This mission will not launch with a crew. For the Delta IV Heavy to carry people for NASA, the vehicle must be human-rated, a process that requires between four to seven years of work and a one-time cost of $500 million. Each human-rated Delta IV Heavy would cost an estimated $300 million per launch.[5]

The Delta IV successfully launched three times in 2010. A Delta IV Medium Plus (4,2) placed GOES-15 into geosynchronous Earth orbit in March, and a Delta IV Medium launched in May to place a Global Positioning System (GPS) satellite into medium Earth orbit. In November, a Delta IV Heavy launched a classified payload for the National Reconnaissance Office. Four Delta IV flights are expected in 2011.

## Falcon 1 – Space Exploration Technologies Corporation

Falcon 1

The two-stage Falcon 1 is a small-class vehicle capable of sending 1,010-kilogram (2,227-pound) payloads into LEO. California-based Space Exploration Technologies Corporation (SpaceX) designed, built, and operates the vehicle, which has been enhanced since its introduction in 2006. Enhancements include an extended first-stage tank to support propellant consumption needs of a single upgraded Merlin engine (Merlin 1C), additional structural support, and a larger, lighter 1.7-meter (5.6-foot) payload fairing.[6]

The 24.7-meter (81-foot) Falcon 1 uses LOX and rocket grade kerosene for the oxidizer and fuel. Helium tanks provide propellant pressurization. Arde Corporation built these helium tanks, which are the same units Boeing uses for its Delta II vehicle. SpaceX designed the reusable aluminum first stage to retain structural strength without pressurization, reducing ground handling difficulties and facilitating reusability. Once its mission is complete, the first stage returns to Earth with the assistance of a parachute, provided by Airborne Systems Corporation. The second stage is made of an aluminum-lithium alloy, similar to the one on the Space Shuttle External Tank. A pneumatic release and separation system facilitates staging. Unlike a system using explosive separators, this approach allows for acceptance testing of flight hardware.

An onboard flight computer and a GPS-supported inertial measurement unit provide the guidance, navigation, and control (GNC) of the Falcon 1. The flight computer enables communication between the payload and the first-stage engine computer while the vehicle is on the ground via an Ethernet. GNC also includes S-band telemetry tracking and downlink, a C-band transponder, tank pressure regulation circuitry, batteries, and power distribution.

SpaceX scheduled nine Falcon 1 launches through 2014, including a test launch. Six flights are for ORBCOMM, an Orbital LEO communication satellite constellation, and two are for clients in Asia and Europe. The Falcon 1 test flight will evaluate the vehicle's recent upgrades and will take place in 2011 from Omelek Island (part of Kwajalein Atoll) in the Pacific Ocean.

### Falcon 9 – Space Exploration Technologies Corporation

The two-stage Falcon 9 entered service in 2010. SpaceX designed Falcon 9 to carry astronauts, as well as satellites, into space. As a result, the vehicle system incorporates a higher factor of safety than if it were designed to carry only uncrewed payloads.

In 2006, NASA selected both SpaceX and Rocketplane-Kistler for the Commercial Orbital Transportation Services (COTS) program to demonstrate the vehicles, systems, and operations needed to support the International Space Station (ISS). SpaceX proposed a system using the Falcon 9 topped with the SpaceX-built Dragon pressurized capsule; Rocketplane-Kistler proposed its K-1 reusable vehicle. However, Rocketplane-Kistler failed to gain additional financing as required by the agreement and was subsequently released from COTS, releasing over $170 million in funding. SpaceX continued work on its Falcon 9 Dragon system. A second round competition for the $170 million followed, with Boeing and Orbital competing for part of the funding. In 2008, Orbital won the competition with its Taurus II proposal.

Falcon 9

In December 2008, NASA awarded a $1.6 billion Commercial Resupply Services (CRS) contract to SpaceX for 12 uncrewed cargo resupply flights to ISS and a $1.9 billion CRS to Orbital for eight flights to ISS, all of which will be licensed by FAA/AST. Under the agreement, SpaceX must launch the Falcon 9 with a test cargo capsule similar in design to an actual cargo vessel (Dragon) that can be used to resupply the ISS. SpaceX successfully launched a Falcon 9 with a Dragon mockup on June 4, 2010, from CCAFS, Florida, and the first test launch with an actual Dragon capsule on December 8, 2010. Two additional Dragon COTS demonstration flights are scheduled for the first half of 2011; ISS resupply flights begin later that year under CRS. SpaceX is contracted with NASA to provide resupply flights to ISS through the end of 2016.[7]

The Falcon 9 is capable of sending 10,450 kilograms (23,050 pounds) to LEO and 4,540 kilograms (10,000 pounds) to GTO from CCAFS. It will perform polar launches from Kwajalein Atoll, lofting payloads of up to 8,560 kilograms (18,870 pounds).

The Falcon 9 consists of two stages. Nine Merlin 1C engines (the same engine used by the Falcon 1) power the first stage and consume LOX and rocket grade kerosene. Routing kerosene fuel, under pressure through the engine's turbopump, enables Thrust Vectoring Control and eliminates the need for a separate hydraulic system. This approach reduces the number of subsystems and thereby reduces the number of failure modes.[8]

The second stage uses only one Merlin C1 engine. By employing ten Merlin C1 engines per mission, SpaceX develops significant engine reliability data. Like the Falcon 1, a pneumatic release and separation system aids stage separation.

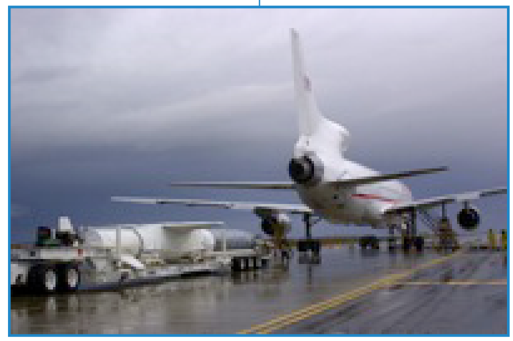
Falcon 9's GNC system takes advantage of legacy systems used on the Falcon 1, but it has been modified as a single fault-tolerant architecture to assure a higher safety factor for human spaceflight.[9]

The vehicle's potentially reusable first stage was not recovered, because the stage had impacted the water with significant force and suffered major damage. An attempt to recover the first stage after splashdown failed. The vehicle carried a fully functional Dragon spacecraft, which returned, as planned, about four hours after on-orbit testing.

SpaceX has a backlog of 33 Falcon 9 launches. Twelve of these are ISS resupply flights, and at least 10 flights are planned to send up the Iridium NEXT second generation constellation. The remaining flights are for commercial clients. SpaceX also plans a heavy version of the Falcon 9, capable of sending 32,000 kilograms (70,548 pounds) to LEO or 19,500 kilograms (42,990 pounds) to GTO. This vehicle will use a single Falcon 9 as the core (both first and second stages), with two Falcon 9 first stages as strap-on boosters. Four Falcon 9 flights are projected in 2011.

## Pegasus XL – Orbital Sciences Corporation

Orbital's three-stage Pegasus XL is a small-class vehicle launched by an L-1011 aircraft from an altitude of 11,900 meters (39,000 feet). Pegasus XL is capable of lifting payloads up to 440 kilograms (970 pounds) to LEO from CCAFS, VAFB, Wallops Flight Facility (WFF), Kwajalein Atoll, and the Canary Islands. Introduced in the summer of 1989, the Pegasus system represents the first successful privately developed launch vehicle in the world; that is, the government did not directly fund development of the vehicle.[10]



Pegasus XL

The vehicle's first stage consists of an Orion 50S XL solid rocket motor and fixed-wing assembly. The second stage is an Orion 50 XL motor, and the third stage is an Orion 38 motor. A Hydrazine Auxiliary Propulsion System fourth stage is available, which improves orbital insertion accuracy. An adapter attaches the payload to the third or fourth stage, and a two-part payload fairing made of composite material encloses the payload.

The vehicle uses a 32-bit computer at the core of its avionics system. The computer interfaces with an inertial measurement unit, vehicle subsystems, and the carrier aircraft, using digital serial data links. This enables rapid integration, testing, and processing of the vehicle, facilitated by commercially available ground support equipment and off-the-shelf hardware.

Beginning in 1990, Pegasus XL has launched successfully 27 times, with a total of 63 payloads successfully placed into orbit. The FAA licensed 16 of the flights, all of which were successful. No Pegasus XL launches were conducted in 2010, but a Pegasus XL is scheduled for launch in 2011 from the Ronald Reagan Ballistic Missile Defense Test Site carrying NASA's Nuclear Spectroscopic Telescope Array satellite.

## Taurus – Orbital Sciences Corporation

Orbital also provides the Taurus XL launch vehicle. The three- to four-stage vehicle is capable of sending 1,590-kilogram (3,500-pound) payloads to LEO.

Four variants of the Taurus are available to customers. Two variants of the Standard Taurus (2110 or 2210) can place between 1,047 kilograms (2,308 pounds) and 1,259 kilograms (2,775 pounds) to LEO or between 695 kilograms (1,532 pounds) and 889 kilograms (1,960 pounds) to a polar orbit. The Taurus XL offers two variants (3110 and 3210), which can place between 1,276 kilograms (2,813 pounds) and 1,458 kilograms (3,214 pounds) to LEO or between 882 kilograms (1,944 pounds) and 1,054 kilograms (2,324

Taurus

pounds) to a polar orbit. The vehicle does not fly GTO missions. All variants of the Taurus are three-stage vehicles, using combinations of the TU-903 or Castor 120 for the first stage, Orion 50ST or Orion 50SXLT for the second stage, and an Orion 50T or Orion 50XLT for the third stage. The optional fourth stage uses the Orion 38 or Star 37 motor. Two payload fairing sizes are available for the Taurus vehicle, depending on payload requirements.[11]

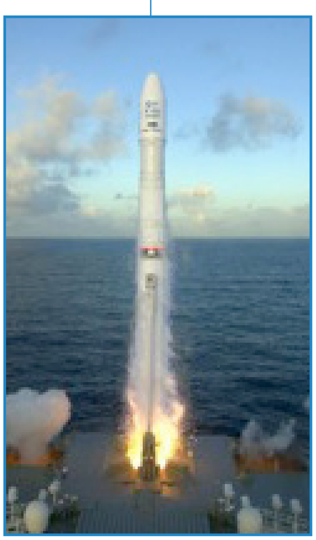
Since its debut in 1994, the Taurus has launched from VAFB eight times and once from WFF, with six successful flights placing nine satellites into LEO. One flight is scheduled in 2011 from VAFB carrying NASA's Glory spacecraft and several cubesats. The vehicle is also approved for launch from CCAFS, though no future flights of Taurus from this site are currently planned.

### Zenit 3SL – Sea Launch AG

Sea Launch AG provides the Zenit 3SL. The heavy-lift launch vehicle serves the heavy-lift segment of the commercial GTO launch market. The launch platform's home port is in Long Beach, California.

Ukrainian-based SDO Yuzhnoye and PO Yuzhmash provide the first two stages, the same as for the Zenit 2 launch vehicle. Russia-based RSC Energia provides the third stage, a Block DM-SL upper stage. Boeing provides the payload fairing and interfaces, as well as flight design. The vehicle provides a payload capacity of up to 6,160 kilograms (13,581 pounds) to GTO. The Zenit 3SL launches from the Odyssey Launch Platform, directly from the Equator at $154^0$ West longitude in the Pacific Ocean.

A single RD-171 engine powers the first stage. (The RD-171 is a variant of the RD-170 that powers the Energia strap-on boosters and is the most powerful liquid-fueled engine currently available.) The engine burns a mix of LOX and rocket grade kerosene. A single RD-120 engine powers the second stage and is also fed with LOX and rocket grade kerosene. A Block DM-SL third stage is also powered by an engine using LOX and rocket grade kerosene.



Zenit 3SL

The FAA licensed all 30 Zenit 3SL launches. Sea Launch expects to perform two commercial missions during 2011 using the Zenit 3SL.

Sea Launch AG is a Swiss-based multinational organization. In October 2010, Sea Launch completed a 16-month-long Chapter 11 restructuring effort. Energia Overseas Limited, an affiliate organization of RSC Energia of Moscow, Russian Federation, acquired a majority ownership stake of the reorganized Sea Launch entity. In 2011, Sea Launch AG will resume launch operations and begin to expand the range of services offered to customers, including additional lift performance of the Zenit 3SL vehicle beginning in 2013.

## Expendable Launch Vehicle Development Efforts

Established corporations and startup companies are currently pursuing several ELV development programs. As in previous years, a major driver for new ELV development is an increasing demand for low-cost launches of small satellites. These include Interorbital System's NEPTUNE 35 and NEPTUNE 45 vehicles, a commercial version of the U.S. Army's Multipurpose Nanomissile System (MNMS), and Lockheed Martin's resurrected Athena series of vehicles. Meanwhile, Orbital continues steady work on its Taurus II vehicle under NASA's COTS program. ELVs under development share the common goal of reducing launch costs to support and further develop the demonstrated market potential.

### Athena 1c and Athena 2c – Lockheed Martin Commercial Launch Services

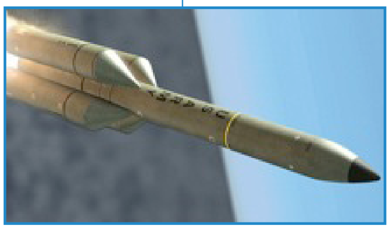
In March 2010, the Lockheed Martin and ATK team announced its intention to reintroduce the Athena series of launch vehicles beginning in 2012 to address a U.S. Government demand for small, quick-turnaround launches. These vehicles are being modernized from the original variants to improve performance.

The Athena Ic and Athena IIc are upgraded versions of the Athena I and Athena II, used during the 1990s. The two-stage Athena Ic will be capable of launching 740-kilogram payloads to LEO. The three-stage Athena IIc rockets will be capable of lifting 1,712 kilograms to LEO. The target orbit is about 185 kilometers at an inclination of 28.5 degrees. Each vehicle will use ATK's Castor 120 solid-rocket motors as a first stage, with the Athena IIc using the same motor for the second stage. A newly developed Castor 30 motor will serve as the upper stage for both vehicles. The Castor 30 was originally developed for Orbital's Taurus II vehicle.

| | |
|---|---|
| Vehicle | Athena Ic/IIc |
| Developer | Lockheed Martin |
| First Launch | 2012 |
| Number of Stages | Athena Ic: 2<br>Athena IIc: 3 |
| Payload Performance kg (lb) | Athena Ic:<br>LEO: 740 (1,631)<br><br>Athena IIc:<br>LEO: 1,712 (3,774) |
| Launch Site | CCAFS<br>Kodiak Launch Complex<br>VAFB<br>WFF |

Lockheed Martin will manage overall operations and Athena launch campaigns, while ATK will be responsible for the motors, payload integration, and structures. The vehicles may launch from CCAFS, VAFB, Kodiak Launch Complex in Alaska, and possibly WFF.[12]

### Multipurpose Nanomissile System – Dynetics/U.S. Army



MNMS

For the first time since Wernher von Braun's Army-funded rocket research was transferred to NASA in 1958, the Army has reentered the launch industry. The U.S. Army Space and Missile Defense Command (USASMDC), Army Forces Strategic Command is working with contractors COLSA Corporation and Dynetics, Inc. to develop a small-class launch vehicle that can send payloads of up to 10 kilograms (22 pounds) to LEO from anywhere in the world. The vehicle is called the MNMS. MNMS is part of the SMDC's Nanosatellite Technology Program, whose other objective is to produce battlefield-relevant satellites at a cost between $300,000 to $1 million per unit.[13]

The Army is pursuing this concept because of the growing need for space-based services by in-theater commanders. With the flexibility inherent in a low-cost, small, mobile system, the Army hopes to provide on-demand launch at potentially high numbers of flights.

At 3.6 meters (12 feet), MNMS will be easily transportable with a small launch infrastructure footprint. The system is for suborbital and orbital missions and will be available commercially after successful development. The Army has spent approximately $7 million on the system and is requesting $17 million more to finish the program. Dynetics developed the main engine, which completed successful testing in July 2010. The engine produces about 3,000 pounds of thrust and is fed a nitrous oxide-ethane blend, a mix that produces less harmful rocket exhaust than solid propellant.[14]

| | |
|---|---|
| Vehicle | Multipurpose Nanomissile System (MNMS) |
| Developer | U.S. Army |
| First Launch | 2013 |
| Number of Stages | 3 |
| Payload Performance kg (lb) | LEO: 10 (22) |
| Launch Site | TBD |

The Army intends to make the MNMS available for commercial use, with an estimated per launch cost of about $1 million, plus payload integration and range costs for a 10-kilogram (22-pound) payload. A suborbital test launch is planned for 2011, followed by an orbital test in 2012.[15]

### NEPTUNE – Interorbital Systems

Interorbital Systems (IOS), headquartered at the Mojave Air and Space Port, California, is developing four modular launch vehicle concepts collectively called NEPTUNE. All the variants consist of Common Propulsion Modules (CPMs). A single CPM includes a rocket engine and propellants (white fuming nitric acid, or WFNA, and Hydrocarbon-X, or HX). The CPMs are arranged in clusters that are described, depending on the type of variant, as stages. Launches will be conducted from the Kingdom of Tonga.

The three-stage, small-class NEPTUNE 30 (N30) will carry 30-kilogram

(66-pound) payloads to polar orbit and will use five CPMs. The NEPTUNE 45 (N45), also a three-stage, small-class vehicle, will loft 45-kilogram (99-pound) payloads to polar orbit using a seven-CPM configuration. The N45 will launch payloads that use either a solid spin-stabilized or a liquid-guided satellite kick motor to be inserted into orbit.


NEPTUNE CPM

IOS expects the NEPTUNE 1000 (N1000), also a small-class vehicle but using 33 CPMs, to handle 1,000-kilogram (2,205-pound) payloads to LEO. The N1000 is also IOS' entrant in the Google Lunar X PRIZE. Finally, the NEPTUNE 4000 (N4000), composed of 84 CPMs, will carry 4,000 kilograms (8,818 pounds) to LEO, making it a medium-class launch vehicle. The N4000 will also be able to carry a crew module, which IOS is developing for tourism. The company also plans to use the N4000 for lunar sample return missions.

Funding for launch vehicle development is coming from the sales of IOS's TubeSat Personal Satellite Kit, which allows clients to purchase all the necessary elements to build a 250-gram satellite for $8,000. Just over 30 TubeSat kits have sold or been reserved.

IOS completed lifting tests of its mobile launch unit in December 2010. Rocket engine hot firings and up to four suborbital test flights of the CPM Test Vehicle are scheduled for early 2011. The first orbital launch is scheduled for the beginning of the third quarter of 2011. The planned manifest for the 2011 inaugural launch of the N45 includes 10 Cubesats and 30 Tubesats.[16]

| | |
|---|---|
| Vehicle | NEPTUNE |
| Developer | Interorbital Systems |
| First Launch | 2011 |
| Number of Stages | N30: 3<br>N45: 3<br>N1000: 3<br>N4000: 3 |
| Payload Performance kg (lb) | N30: LEO 30 (66)<br>N45: LEO 45 (99)<br>N1000:<br>LEO 1000 (2,205)<br>N4000:<br>LEO 4,000 (8,818) |
| Launch Site | Kingdom of Tonga |

Twenty additional committed payloads are in various phases of funding. Academic, artistic, private sector, and corporate groups from Peru, Austria, Mexico, Germany, Vietnam, Pakistan, and the Dominican Republic are currently arranging to fly with IOS on the N45's inaugural flight. A number of private companies and several U.S. military entities are also arranging their own dedicated launches for orbits that they cannot easily reach as secondary payloads.[17]

### Taurus II – Orbital Sciences Corporation

Orbital is currently developing the Taurus II, an intermediate-class, two-stage orbital launch vehicle. The vehicle will be capable of placing payloads with masses up to 6,500 kilograms to LEO, and it will be launched from Virginia's Mid-Atlantic Regional Spaceport (MARS), though additional launch sites are planned depending on customer needs. The Taurus II is a completely different vehicle from the Taurus described in an earlier section.

Taurus II

Orbital began developing the Taurus II to address the medium- to intermediate-class payload markets. In addition, the company submitted its vehicle concept for NASA's COTS demonstration contract, winning a $170 million contract in 2008. In December of that year, Orbital won a CRS contract to deliver cargo in pressurized modules to the ISS. Orbital is required under contract to provide eight flights to ISS through 2016.[18] Only one test flight is planned for Taurus II under COTS.

Two Aerojet AJ26-62 engines burning liquid oxygen and rocket grade kerosene will power the first stage. The AJ26-62 engine is based on the NK-33, designed in the 1960s to power the first stage of the Soviet Union's N-1 vehicle, but upgraded using Aerojet components and electronics. After cancelling human missions to the Moon, the Soviet Union stockpiled about 150 NK-33 engines; Aerojet purchased 37 of them in the 1990s. The two engines, thrust vectoring components, thrust frame, and associated plumbing are collectively called the Main Engine System.

The second stage is a Castor 30A solid motor with thrust vectoring. Orbital will offer a Star 38 third stage depending on mission requirements. Topping off the vehicle is a 3.9-meter-diameter composite payload fairing. The second stage is also home to the avionics module, or avionics "ring." The avionics module contains the Modular Avionics Control Hardware that provides power distribution; Ethernet-based communications with vehicle subsystems, launch equipment, and payload; acquisition and telemetry data; vehicle stage interfaces; and range ordnance control.[19]

| | |
|---|---|
| Vehicle | Taurus II |
| Developer | Orbital Sciences Corporation |
| First Launch | 2011 |
| Number of Stages | 2 |
| Payload Performance kg (lb) | LEO: 6,500 (14,330) |
| Launch Site | MARS |

Orbital has a backlog of eight Taurus II launches through 2016, with flights beginning in 2011, which are all under the NASA CRS contract.

## Sounding Rockets

Sounding rockets typically employ solid propellants, making them ideal for storage. They differ from amateur or hobbyist rockets in that they climb to higher altitudes, but do not enter a sustainable orbit, and they carry out missions on behalf of commercial, government, or non-profit clients. Sounding rockets are used for atmospheric research, astronomical observations, and microgravity experiments that do not require human tending.

Three ELV sounding rocket systems are currently available to U.S. customers, with two that have a long history of providing highly reliable services. Canada-based Bristol Aerospace has provided sounding rockets that have been used in the U.S. for decades. They are available to the U.S. scientific community through the NASA Sounding Rockets Operations Contract (NSROC) managed by the NASA Sounding Rockets Program Office (SRPO), located at WFF in Virginia.

### Black Brant – Bristol Aerospace, Ltd.

The Black Brant sounding rocket system is a flexible, multi-configuration family of upper- and exo-atmospheric launch vehicles. Over 1,000 Black Brant rockets have launched since production began in 1962. The Black Brant rocket motor, the related Nihka rocket motor, and supporting hardware are all manufactured in Canada by Bristol Aerospace, a subsidiary of Magellan Aerospace Limited. U.S.-manufactured Terrier, Talos, and Taurus motors are on several Black Brant configurations. In the United States, the NASA Sounding Rocket Program has made extensive use of the Black Brant vehicles.

The Black Brant family of vehicles can launch a 113-kilogram (250-pound) payload to an altitude of at least 1,400 kilometers (870 miles), a 454-kilogram (1,000-pound) payload to an altitude of at least 400 kilometers (250 miles), or a 680-kilogram (1,500- pound) payload to an altitude of at least 260 kilometers (160 miles). These vehicles can provide up to 20 minutes of microgravity time during a flight. Payloads with diameters of up to 56 centimeters (22 inches) have flown successfully.

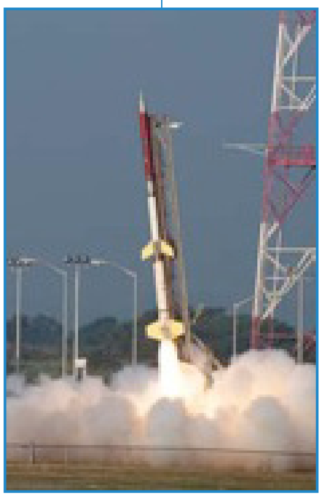
The smallest version of the Black Brant family is the Black Brant V, which is 533 centimeters (210 inches) long and 43.8 centimeters (17.24 inches) in diameter. The rocket produces an average thrust of 75,731 newtons (17,025 pounds-force). The Black Brant V motor can be used on its own, as a single-stage vehicle, or used as the second or third stage in larger, multi-stage versions of the Black Brant. The most powerful configuration of the family, the Black Brant XII, is a four-stage vehicle that uses the Black Brant V motor as its third stage and Bristol Aerospace's Nihka motor as its fourth stage.

The Black Brant remains in active use today, after nearly 50 years of reliable service. The Black Brant sounding rocket system continues to be the workhorse of the NASA Sounding Rocket Program.

Black Brant

### Improved Orion and Terrier-Improved Orion – NASA Sounding Rockets Program Office

NASA's Sounding Rockets Program Office (SRPO), located at WFF in Virginia, conducts sounding rocket launches for NASA, universities, and other customers. Supplied vehicles include Bristol Aerospace's Black Brant series in several vehicle configurations, from a single-stage vehicle to a four-stage vehicle stack (described in a previous section); the Improved Orion; and the Terrier-Improved Orion.[20]


Terrier-Malemute

WFF provides both engineering and mission operations support to the commercial launch industry. Through NASA Space Act Agreements, WFF engineering personnel and laboratories frequently support commercial space technology development and testing. WFF also provides launch range services to the commercial launch industry, either directly or through partnership with the FAA-licensed MARS. However, NASA cannot offer commercial flights aboard government-owned suborbital vehicles; the agency can support only preparation and mission operations needs for commercial users.

NASA's SRPO integrates the subassemblies, which, with the exception of Black Brant, consist of military surplus Orion and Terrier motors. Payloads are typically limited to science and hardware testing. SRPO conducts about 15-20 sounding rocket launches per year from WFF, Poker Flat Research Range in Alaska, White Sands Missile Range in New Mexico, and Andoya Rocket Range in Norway.

The Terrier-Improved Orion consists of a 46-centimeter (18-inch) diameter Terrier first stage and a 36-centimeter (14-inch) diameter Improved Orion second stage. This vehicle, which has a diameter of 14 inches, can carry a payload of up to 363 kilograms (800 pounds) to an altitude of 75 kilometers (47 miles) or 100 kilograms (220 pounds) to an altitude of 225 kilometers (140 miles). The Terrier-Orion is launched from WFF.

SRPO launched three Terrier-Orion vehicles in 2010, with the first launched from Poker Flat Research Range on February 2, 2010. Two others were launched from WFF, on June 24, 2010, and September 21, 2010. A Terrier-Improved Malemute launched on March 27, 2010, to test the Malemute upper stage and carry two student cubesats. The Malemute is a surplus missile motor, and it is rarely used by SRPO.

### Shadow I and II – Lunar Rocket and Rover Company

With development on the orbital Shadow III ongoing, Lunar Rocket and Rover Company continues to provide sounding rocket services to customers. In 2010, the company successfully launched a new version of the Shadow I, called the Shadow IE. The vehicle successfully reached an altitude of 115 kilometers (71.5 miles) and successfully deployed a test balloon, which was tracked by the French Radar Ship Monge. The payload successfully transmitted telemetry from launch to apogee, considered a significant milestone for the company since previous linkages failed at around 15,545 meters (51,000 feet). The 2010 launch aimed to test a new payload ejection system, a new rocket balloon instrument (Robin) sphere inflation system, wind data capture, and an ascent tracking system.[21]


Shadow I

In addition, the Lunar Rocket and Rover Company has three school-built payloads awaiting launch on a Shadow I, and the company is exploring financing options. All three payloads were built as a cooperative effort between middle school and university students.

## ELV Development Efforts Not Detailed in this Report

During the past decade and a half, several companies have been established to develop new orbital ELVs and RLVs. Earlier editions of this report profiled many of these. Inevitably, some of these companies will change their business plans or will encounter financial or technical difficulties. Table 3 on the following page identifies five orbital vehicle systems developed through private funding that were profiled in earlier reports, but not in this edition. AirLaunch's QuickReach vehicle effort was terminated when the company filed for bankruptcy. Shadow III, under development by Lunar Rocket and Rover Company, is not being pursued at this time due to funding shortfalls; however, the company currently provides sounding rocket services. In the other three cases, FAA/AST could not verify the status of vehicle developments.

| Vehicle | Vehicle Type | Company | Description | Remarks |
|---|---|---|---|---|
| Athena III | Orbital | PlanetSpace | Three-stage solid propellant system designed to address CRS. Team included Lockheed Martin, Boeing, and ATK. | NASA did not select the PlanetSpace team, though the company announced it would pursue Athena III, nevertheless. No updates on the Athena III have been posted since 2008. |
| Eagle S | Orbital | PlanetSpace | Seven variants based on the LGM-118A Peacekeeper Intercontinental Ballistic Missile (MX). | No updates on the Eagle S series of vehicles have been posted for 2010. |
| Nanosat Launch Vehicle | Orbital | Garvey Spacecraft Corporation | Two-stage, liquid propellant vehicle capable of sending 10 kilograms to SSO. | In October 2010, Garvey Spacecraft Corp. delivered two rockets to Orbital Technologies Corp. (ORBITECH) for engine integration and testing. Launches of these vehicles are expected in 2011.[20] |
| QuickReach | Orbital | AirLaunch, LLC | Air-launched, two-stage ELV capable of sending 450 kilograms (1,000 pounds) to LEO. | AirLaunch LLC ceased operations in 2008. |
| Shadow III | Orbital | Lunar Rocket and Rover Company | Three-stage, solid propellant orbital launch vehicle capable of sending payloads of 32 kilograms (71 pounds) to LEO. | Funding options to complete development are currently being explored. |

Table 3: ELV development efforts not detailed in the report.

# REUSABLE LAUNCH VEHICLES

Vehicles that access outer space, operate within that environment, and returning safely so they can be used again are called reusable launch vehicles (RLVs). Some RLVs are designed for suborbital trajectories; that is, they do not attain enough velocity to enter into a sustainable orbit around the Earth. RLVs that enter orbit are launched aboard expendable launch vehicles (ELVs) or launched from airplanes. The launch industry is also exploring single stage to orbit (SSTO) vehicles, which are capable of operating from the ground, in the air, and in space as a single unit. SSTO remains a significant engineering challenge despite being investigated as a space access option for many decades.

There are no crewed RLVs currently in operation in the United States. However, several companies have completed significant milestones in crewed RLV development, with one (Scaled Composites) already conducting flight tests. The first part of this section describes proposed commercial suborbital and orbital RLVs in development or under study. The second part describes reusable sounding rockets, which at this time only includes UP Aerospace's commercially available reusable sounding rocket.

The third chapter of this report discusses reusable cargo and passenger capsules, which are transport vessels available for commercial use launched atop an ELV or RLV. The Eependable Launch Vehicles chapter discusses the proposed reusable first stage of the Falcon 9.

## Reusable Launch Vehicle Development Efforts

### SpaceShipTwo/WhiteKnightTwo – Scaled Composites, Virgin Galactic

In April 2003, California-based Scaled Composites announced that it was developing a vehicle capable of winning the Ansari X PRIZE. This prize would award $10 million for the first, privately financed, piloted vehicle demonstrating two successful suborbital space flights (100 kilometers, or 62 miles) within two weeks. Scaled Composites described this effort as a Tier One development program for a future vehicle. The vehicle system employed a conventional jet airplane, called the White Knight, that carried the rocket-powered spacecraft SpaceShipOne (SS1) to an altitude of 14 kilometers (8.7 miles) before releasing. All flights flew out of Mojave Airport. Paul Allen, co-founder of Microsoft, provided substantial financial backing through a joint venture called Mojave Aerospace Ventures.

On April 1, 2004, FAA/AST issued a commercial launch license to Scaled Composites authorizing the company to operate a rocket-powered vehicle designed for use in space. On June 21, 2004, with astronaut pilot Mike

SpaceShipTwo

Melvill at the controls, SS1 successfully completed a test flight into space, achieving an altitude of 100 kilometers (62 miles). On September 29, 2004, SS1, again piloted by Melvill, achieved an altitude of 103 kilometers. On October 4, 2004, pilot Brian Binnie captured the Ansari X PRIZE for Mojave Aerospace Ventures by achieving an altitude of 112 kilometers (70 miles) within the required two-week timeframe. After this last and 14th flight of SS1, Scaled Composites had enough test flight data to begin work on a new vehicle system.

In 2005, Scaled Composites and Virgin Group formed a partnership called The Spaceship Company, which licensed the SS1-related technology developed by Mojave Aerospace Ventures. This partnership enabled financing for the design, construction, and delivery of a fleet of SpaceShipTwo (SS2) vehicles, based on SS1, and their carrier aircraft, called WhiteKnightTwo. Under this arrangement, Scaled Composites continues to manufacture the vehicles. Scaled Composites defines the SS2 effort as Tier 1b, another step on the way to orbit (Tier Two).[1]

SS2 is a spacecraft physically similar to SS1 except in size. It uses the same feathered reentry system employed by SS1, often described as a shuttlecock. This system allows for slow reentry velocities, which reduces the heat build-up of reentry. SS2 is designed to carry six passengers and two crewmembers. It will be powered by a single hybrid solid rocket engine called RocketMotorTwo, developed by Scaled Composites and Sierra Nevada Corporation. SS2 is designed to reach an altitude of 110 kilometers (68 miles). Five SS2 vehicles are planned for Virgin.[2]

The seven-phase SS2 test flight program began in October 2009 with ground tests and culminated in suborbital launch tests, all taking place at Mojave Air and Space Port, now an FAA/AST-licensed commercial spaceport. Phase one of the test program involved taxiing and ground operations. The second phase of the program, captive carry flights of the uncrewed SS2 (named VSS Enterprise) and WhiteKnightTwo (named VMS Eve), commenced on March 22, 2010.[3] A second flight followed on May 16. Both tests were completed successfully. Phase three of the test program, captive carry with a pilot at the controls of VSS Enterprise, began on July 15 and was repeated on September 30. Successful completion of both tests meant the system was ready for Phase four of the program, piloted glide flights of VSS Enterprise. The first of these flights took place on October 10, lasted 13 minutes, and concluded successfully.[4] Phase four testing concludes with glides featuring short bursts from the vehicle's rocket engine.[5]

Test flights that do not use a rocket require an FAA experimental airworthiness license, which Scaled Composites secured in 2008 for both WhiteKnightTwo and SS2.[6] Once a rocket engine is integrated with SS2, the vehicle will require an FAA/AST license before operating. As of December 2010, this license was still pending.[7]

Many more test flights await VSS Enterprise before commercial operations. These necessary test flights consist of rocket-powered, supersonic, high-altitude flight (Phase Five), suborbital flights (Phase Six), and safety-of-flight demonstrations to earn FAA/AST approval for commercial operations (Phase Seven).[8] The commercial flights will take place from New Mexico's Spaceport America, currently slated for completion in 2011.[9]

Commercial flights of VSS Enterprise and its companion vehicles are expected to begin in the latter half of 2011. All of these flights, brokered by Virgin Galactic, a subsidiary of Virgin Group, will launch from Spaceport America, which became an FAA-licensed spaceport in December 2008. By November 2010, Virgin Galactic obtained deposits from 380 individuals for a total of $50 million. The objective is to secure deposits from 500 people before commercial operations begin.[10]

## Lynx – XCOR Aerospace

Founded in 1999, XCOR Aerospace was established by engineers that worked on Roton, a unique vertical take-off and landing RLV testbed that combined a rocket and a helicopter. XCOR's main objectives are to produce rocket engines for the RLV market and develop an RLV. XCOR is modifying a piston-based pumping system that can handle cryogenic liquids for rocket engines as an alternative to traditional turbopumps.

Beyond its growing experience with rocket engine technology, XCOR developed two test vehicles, EZ-Rocket and X-Racer. XCOR used the EZ-Rocket, a kit plane designed by Burt Rutan, modified by XCOR with an engine conversion, new tanks, and some new instrumentation, as a technology demonstrator. The vehicle retired in 2005 after it helped XCOR test a reusable rocket engine as part of an integrated flight system and establish low-cost operational procedures to enable rapid turn-around between flights. XCOR also developed X-Racer for the Rocket Racing League. The X-Racer allowed XCOR to pursue improvements that were impractical to retrofit on EZ-Rocket.[11]

Lynx

Experiences gleaned from the EZ-Rocket and X-Racer inform development of the Lynx Mark I, a prototype vehicle designed to conduct test flights to an altitude of about 61 kilometers (38 miles). The Lynx Mark I takes off and lands like an airplane. The vehicle employs four XR-5K18 rocket engines developed by XCOR and powered by liquid oxygen (LOX) and rocket grade kerosene. Pennsylvania-based Airgas, Inc. will provide LOX, helium, and nitrogen for XCOR through 2025, through a contract signed in March 2010.[12] Successful hot fire testing of the XR-5K18 engine was completed in 2008, and full testing continues.

In September 2010, XCOR successfully tested a Lynx scale model in a wind tunnel at NASA's Marshall Space Flight Center, as part of a Cooperative Research and Development Agreement between the company, NASA, and the Air Force Research Laboratory's (AFRL) Air Vehicles Directorate. XCOR expects test flights of the Lynx Mark I to begin in 2011 from Mojave Air and Space Port. After successful testing, the Lynx Mark I will be available to carry small payloads of 120 kilograms (265 pounds) internally.

The two-seat Lynx Mark II is XCOR's operational version of the Lynx suborbital RLV program. This vehicle will send a pilot, spaceflight participant, and small payload (120 kilograms, or 265 pounds) to an altitude of 100 kilometers (62 miles). The spaceflight participant, who might also be paid to tend a payload, sits just behind and to the pilot's right. Occupants will be required to wear pressure suits at all times. The Lynx Mark II is expected to fly in late 2012 or early 2013.

XCOR continues to work with the U.S. Department of State on a wet lease deal with South Korea-based Yecheon Astro Space Center. This center selected XCOR in December 2009, as its preferred supplier of suborbital space launch services. A wet lease means the center does not purchase the vehicle; rather, it purchases the right to lease the vehicle and pays XCOR to operate it. XCOR will provide services to the center using the Lynx Mark II as part of the deal.[13]

XCOR and Space Experience Curaçao (SXC) of Netherlands Antilles also signed a wet lease partnership agreement in October 2010. In this deal, SXC markets space tourism flights aboard the Lynx, beginning January 2014. Discussions between the U.S. Government, XCOR, Curaçao Airport Holding, and other parties are underway to allow use of the Lynx at Curaçao.[14]

XCOR and Masten Space Systems also signed an agreement in 2010 to work jointly on lander projects, combining XCOR's experience with engines and Masten's success with vertical take-off and landing vehicles. Details about these landers can be found in the section on Masten.[15]

## New Shepard – Blue Origin

Blue Origin is pursuing the challenge of designing reusable vertical take-off, vertical landing (VTVL) space launch vehicles for human spaceflight. VTVL vehicles take off vertically like a conventional rocket, but then perform a powered vertical landing for recovery and reuse. Vehicle manufacturing is done at Blue Origin's headquarters near Seattle. Blue Origin conducts flight testing at its launch site in West Texas near the town of Van Horn. Blue Origin is the only space launch company in the United States, and possibly the world, operating its own dedicated launch site.[16]

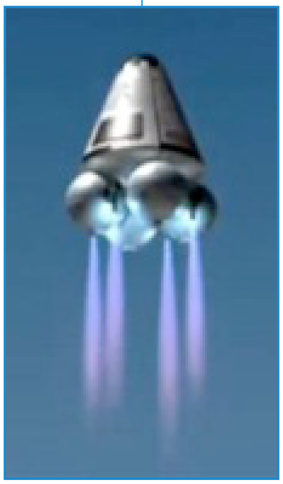
Goddard

In November 2006, the company successfully tested its Goddard low-altitude VTVL vehicle at the West Texas Launch Site. Goddard represents a first step in Blue Origin's overall New Shepard program. Blue Origin is developing other suborbital vehicles to carry three or more astronauts to altitudes above 325,000 feet (above 100 kilometers). The company will later pursue orbital launches.

In 2010, Blue Origin continued working with various colleges and universities, as part of its pathfinder program to enhance services offered to those seeking suborbital science research and education missions.[17]

Also in 2010, NASA signed a Space Act Agreement with Blue Origin for $3.7 million as part of the agency's Commercial Crew Development (CCDev) program. Under the agreement, Blue Origin continued development of two subsystems for its orbital Space Vehicle. The first is a "pusher" crew escape system. In the past, crew escape systems have been of the "tractor" variety, in which a launch escape tower pulls a capsule away from the launch vehicle. This introduces a flight safety event when there is no emergency, as the tractor must be jettisoned. Blue Origin is developing a "pusher" system mounted at the rear of the capsule. This allows the escape system to remain with the vehicle when there is no emergency, avoiding the flight-safety risk of the jettison event. Under CCDev, Blue Origin also continued development of a subscale composite pressure vessel, which is lighter and provides more redundant safety protection for astronauts during flight. Blue Origin was the first of NASA's CCDev partners to successfully complete all milestones co-funded by NASA under the program. Testing these technologies will inform development of Blue Origin's orbital Space Vehicle, which the company plans to launch aboard an Atlas V and eventually on Blue Origin's own reusable booster system.[18]

### Super-MOD, Tube, SOST – Armadillo Aerospace



SOST

Armadillo Aerospace continues its extensive flight-testing program for suborbital science and space tourism vehicles. Early successes with the Super-MOD lander vehicle led to a launch services contract with NASA under the Commercial Reusable Suborbital Research (CRuSR) program. Armadillo reportedly received $225,000 of the total $475,000 contract, with Masten receiving the remaining $250,000.[19] NASA contracted with Armadillo for three launches of the company's Super-MOD vehicle, subject to FAA launch license approval.[20] These are pathfinder projects to help NASA gain experience with payload integration and launch operations under the CRuSR program, before its official start in 2011. None of the launches by Armadillo or Masten will be designed to reach beyond an altitude of 100 kilometers (62 miles).

Also in 2010, Armadillo introduced the reusable, 38-centimeter (15-inch) diameter Tube vehicle, capable of reaching beyond 100 kilometers (62 miles) depending on payload mass. Tube can be flown to these altitudes under an amateur classification or waiver, depending on location. The vehicle uses a LOX-alcohol engine developed by Armadillo and is designed to be a low-cost, reusable option to the Super-MOD and its derivatives. Tube, which will be tested in January 2011, will be flown out of Spaceport America.

Armadillo also made progress on its reusable Suborbital Space Transport (SOST) vehicle, a four-tank configured system capable of carrying a capsule for crewed or uncrewed missions. SOST test flights are scheduled for 2011, with operations beginning in late 2012 to early 2013. By early 2011, following engineering evaluations of all its vehicles, Armadillo will make a decision about the optimal configuration for SOST. In April 2010, Armadillo signed an agreement with Space Adventures to market Armadillo's suborbital services using SOST.

The company expects a busy schedule in 2011, with test launches conducted at Caddo Mills Airport in Texas, Spaceport Oklahoma, and Spaceport America.

### XA 1.0 – Masten Space Systems

Mojave-based Masten develops and markets igniters and engines. It also provides aerospace consulting services and develops experimental launch vehicles. Masten is pursuing a reusable, vertical take-off, vertical landing suborbital vehicle system. Masten's Extreme Altitude-1.0, or XA-1.0, is an uncrewed vehicle designed to lift 100-kilogram (220-pound) payloads to an altitude of 100 kilometers (62 miles) or more. The date of the first launch of the XA-1.0 has not yet been released. Masten is developing several prototypes to test various approaches and systems in preparation for XA-1.0.

Xoie

In December 2007, Masten flight-tested its first prototype vehicle, called the XA-0.1A. The flight ended when the engines shut down due to a faulty computer command, and the vehicle crashed to the ground. The next prototype XA-0.1B (Xombie) was used for low-altitude, low-speed testing and became Masten's entry to the NASA-funded Northrop Grumman Lunar Lander X PRIZE Challenge in 2009. The Masten team won the Level One second prize in the competition. The vehicle also successfully demonstrated the first in-air engine re-light for a vertical take-off, vertical landing vehicle. Later, Masten's XA-0.1E (Xoie) won the Level Two first prize of the competition. Xoie has undergone refitting during 2010 to enable carrying a 10-kilogram (22-pound) payload to an altitude of 30 kilometers (19 miles).

Masten plans two major upgrades of the Xoie vehicle. The first upgrade, called Foxie, is designed to lift 10 kilograms (22 pounds) above the 30-kilometer (19-mile) mark. Following successful testing of the Foxie version, Masten will outfit the vehicle with bigger tanks, increasing its capacity to send 47 kilograms (104 pounds) to a 100-kilometer (62-mile) altitude, with flights beginning in 2011. This version of the vehicle is nicknamed Xogdor and will form the basis of the commercially available suborbital XA-1.0 vehicle.

In 2010, NASA awarded Masten $250,000 as part of a CRuSR contract. In this contract, Masten provides four flights of a reconfigured Xoie vehicle, called Xaero, for launching test payloads from the Mojave Air and Space Port and Cape Canaveral Spaceport's LC-36.[21] The first two flights, planned for January 2011, will reach an altitude of approximately five kilometers (three miles). The other two flights will reach about 29 kilometers (18 miles) and include an in-flight engine shutdown.[22]

## RLVs not detailed in this report

During the past decade and a half, several companies have been established to develop suborbital RLVs. Many of these have been profiled in earlier editions of this report. Inevitably, some of these companies will change their business plans or will encounter financial or technical difficulties. Table 4 identifies three suborbital RLVs developed through private funding that were profiled in earlier reports but not in this edition. In June 2010, Rocketplane XP filed for bankruptcy. In the other two cases, not enough activity occurred in 2010 to warrant a detailed profile.

| Vehicle | Vehicle Type | Company | Description | Remarks |
|---|---|---|---|---|
| MICHELLE-B | Suborbital | TGV Rockets | Vertical take-off /vertical landing vehicle features reusable rocket boosters topped with a capsule rounded with viewing ports. Vehicle returns with aid of deployable air brakes. | While work on engine development (TGV-RT30) and aerospace consulting continues, development of MICHELLE-B is delayed due to lack of funding. |
| RocketPlane XP | Suborbital | Rocketplane | Vehicle plan is similar to a modified business jet, equipped with two jet engines and a rocket engine. | Rocketplane declared bankruptcy in June 2010.[23] |
| Silver Dart | Orbital | PlanetSpace | Vehicle plan is based on the FDL-7 designed by the U.S. Air Force Flight Dynamics Laboratory and NASA's X-24B test aircraft. Designed to be launched atop an ELV. | No updates on the Silver Dart have been posted for 2010. |

Table 4: RLV development efforts not detailed in the report.

## Reusable Sounding Rockets

SpaceLoft XL

### SpaceLoft XL – UP Aerospace, Inc.

UP Aerospace designed, developed, and launches the SpaceLoft XL reusable sounding rocket. UP Aerospace, Incorporated is headquartered in Farmington, Connecticut, with business and engineering offices in Highlands Ranch, Colorado. The rocket, six meters (20 feet) tall and 25 centimeters (10 inches) in diameter, can carry up to 50 kilograms (110 pounds) of payload to a maximum altitude of 225 kilometers (140 miles). UP Aerospace markets the SpaceLoft XL vehicle to serve educational and research markets, such as microgravity and atmospheric sciences experiments, as well as commercial applications, including product marketing and novelty promotion. UP Aerospace also provides research and development, testing, and range services for commercial aerospace companies at Spaceport America, New Mexico. Spaceport America is the primary launch site for UP Aerospace and its SpaceLoft XL vehicle.

The first successful SpaceLoft XL launch was on April 28, 2007, at Spaceport America in New Mexico. The most recent launch was on May 4, 2010, when a SpaceLoft XL (SL-4 mission) successfully launched several payloads, including some for the Air Force Research Laboratory's Operationally Responsive Space Office. The rocket reached an apogee of 113.8 kilometers (70.7 miles), with all payloads returned to customers in less than four hours from launch.

There were no launches in 2008, but three in 2009. The first, the SpaceLoft XL SL-3 mission on May 2, 2009, carried student research experiments. The second launch occurred on August 4, 2009, and lofted a ground-launched UAV prototype for the aerospace company Moog-FTS with a turnaround of six weeks from planning start to launch. The third flight, on October 10, 2009, was a successful launch of an experimental test flight vehicle for Lockheed Martin.

# REENTRY VEHICLES AND IN-SPACE TECHNOLOGIES

Expendable launch vehicles (ELVs) and reusable launch vehicles (RLVs) send payloads into space, and most payloads, such as satellites, enter orbit. Some payloads are suborbital, including science instruments launched aboard sounding rockets. In some cases, however, a payload is a method of transporting cargo or people. This system of in-space transportation completes a transportation circuit between the location in orbit where the launch vehicle deposits the payload and a specific destination in space, like a space station or celestial body. Either an onboard crewmember or a remote operator can control in-space transportation vehicles. Some in-space transportation vehicles, particularly those carrying people, are designed to return safely to Earth intact. Therefore, reentry vehicles require adequate protection from atmospheric friction during reentry. Other in-space transportation vehicles, like the uncrewed Russian Progress spacecraft, burn up in the atmosphere after offloading cargo to the International Space Station (ISS).

Early examples of reentry and in-space transportation vehicles have been government-operated, including one-person vehicles like the United States Mercury (1959-1963) and Soviet Vostok (1960-1963). Later versions include multi-crew vehicles like the United States Space Shuttle (1981-2011), Russian Soyuz (1966-present), and Chinese Shenzhou (1999-present). Beginning in 2011, commercial systems will transport people and goods for the first time in history. U.S. companies build and operate all of the planned vehicles. The U.S. Government is the primary customer in all cases, but the space industry hopes that with experience, and as the in-space transportation market matures, economies of scale will develop and new customers will emerge. Currently, the ISS is a driver for commercial in-space transportation. The possibility that U.S.-based Bigelow Aerospace will develop a commercial space station is another driver. With the possibility of U.S. Government and allied missions to near Earth asteroids and the Moon within the next few decades, demand for commercial in-space transportation may increase.

Government-funded vehicles, like the Space Shuttle, the European Automated Transfer Vehicle (ATV), the Russian Progress, and the Japanese H-IIA Transfer Vehicle (HTV), currently provide cargo services to ISS. The Space Shuttle and Russian Soyuz systems currently provide crew delivery and return. Anticipating the retirement of the Space Shuttle Program, NASA decided several years ago to investigate commercial options for ISS support. The agency has since become the chief enabler of both commercial cargo and commercial crew transportation in the U.S. NASA hopes that monies competitively allocated to industry for either purpose will evolve into sustainable in-space transportation. NASA has currently contracted with Lockheed Martin to build the Orion spacecraft to carry humans to ISS starting 2016, and eventually the moon and Mars. Orion is a government led development effort and therefore not included in this report.

In 2006, NASA announced the $500 million Commercial Orbital Transportation Services (COTS) program. COTS focuses exclusively on designing and developing commercial cargo services to the ISS. In late 2006, NASA entered into two Space Act Agreements under COTS with SpaceX ($278 million) and Kistler Aerospace ($207 million). However, due to financial and technical difficulties within Kistler, NASA decided to terminate the agreement with the company (which spent $32 million by that time) and open the remaining $175 million for new proposals. After a new round of competition, Orbital Sciences Corporation (Orbital) won, and NASA entered into a Space Act Agreement with that company in 2007. Under COTS, SpaceX develops the Falcon 9 vehicle and the Dragon cargo capsule, and Orbital develops the Taurus II vehicle and Cygnus capsule for cargo delivery to the ISS.

In 2008, NASA awarded two Commercial Resupply Services (CRS) contracts to SpaceX and Orbital. SpaceX won a contract valued at $1.6 billion for 12 flights through 2015, and Orbital won a $1.9 billion contract for eight flights during the same period.[1] Operational flights under these contracts are expected to begin in 2011. Table 5 lists all in-orbit vehicles currently in development.

| Vehicle | Company | Type | Planned First Flight | Description |
|---|---|---|---|---|
| CST-100 | Boeing | Crewed | 2015 | Reusable pressurized crew-carrying capsule with propulsion module aft of capsule. Designed to access ISS and planned Bigelow Aerospace commercial space station. Launched by either Atlas V or Delta IV. |
| Cygnus | Orbital | Uncrewed | 2011 | Reusable pressurized cargo-carrying vehicle launched by Taurus II from Mid-Atlantic Regional Spaceport in Virginia. Designed to access ISS. |
| Dragon | SpaceX | Crewed and Uncrewed | 2011 | Reusable pressurized Spacecraft capsule for crews or cargo, with unpressurized Trunk aft of capsule featuring equipment bay, solar arrays, and, if required, DragonLab. The Spacecraft is capped with a removable Nosecone-protecting docking collar. Designed to access ISS. Launched by Falcon 9 from CCAFS. |
| Dream Chaser | Sierra Nevada Corp. | Crewed | 2014 | Reusable space plane concept based on the HL-20 designed to access ISS. Expected to be launched aboard an Atlas V. |

Table 5: Commercial reentry and in-space vehicles currently in development.

In terms of crew delivery and return to the ISS, NASA initiated the $50 million Commercial Crew Development (CCDev) program in 2010, funded through the 2009 American Recovery and Reinvestment Act.[2] Like COTS, CCDev focuses exclusively on developing systems to send people to ISS. The CCDev program does not include actual crew transportation services. In 2010, NASA awarded CCDev contracts to Sierra Nevada Corporation ($20 million, for the Dream Chaser vehicle proposal), Boeing ($18 million, for the CST-100 vehicle proposal), United Launch Alliance ($6.7 million, for human rating the Atlas V and Delta IV), Blue Origin ($3.7 million, for a launch abort system and other components), and Paragon Space Development Corporation ($1.4 million, for a modular life-support system). Shortly after the NASA Authorization Act of 2010 was signed into law on October 11, 2010, the agency announced it is seeking proposals for a second round of CCDev awards totaling $200 million,[3] contingent on Congressional appropriations.[4] Awards will be announced in March 2011.

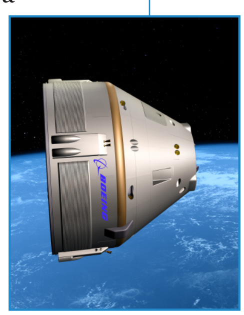
ISS will be busy next year, as commercial access begins to ramp up. In 2011, there are plans for visits to the ISS by one (and possibly two) Space Shuttle flights, five Russian Progress spacecraft, one European ATV, one Japanese HTV, three SpaceX Dragons, and one Orbital Cygnus.[5]

Table 6 on the following page is a summary of COTS, CRS, and CCDev Space Act Agreements and a projection of COTS and CCDev funding, based on the NASA Authorization Act of 2010.

## Commercial Reentry Vehicles and In-Space Transportation Currently in Development

### CST-100 – Boeing and Bigelow Aerospace

In September 2009, Boeing submitted a proposal for NASA's CCDev program, in partnership with Bigelow Aerospace. NASA awarded $18 million to the team in February 2010, under a Space Act Agreement for the Crew Space Transportation (CST)-100 program. Boeing's business plan depends on government funding to support capability development. The business case is built on transportation to the ISS, with NASA as a foundational customer, and services to other low Earth orbit (LEO) destinations as a significant potential upside. Boeing continues working with Bigelow Aerospace, supporting their Orbiting Space Complexes as an expansion of the market. According to Boeing, transportation to Bigelow's commercial space station is expected to become operational in 2015, the year CST-100 becomes available.[6]


CST-100

CST-100 is designed for missions to LEO only. The vehicle will be capable of carrying either cargo or up to seven people to a LEO

| Program | Year of Space Act Agreement | Value of Space Act Agreement | Companies | Vehicles and Technologies |
|---|---|---|---|---|
| COTS | 2006 | $278 million | SpaceX | Dragon |
| COTS | 2006 | $207 million | Kistler* | K-1 |
| COTS | 2007 | $175 million | Orbital | Cygnus |
| CRS | 2008 | $1.5 billion | SpaceX | Dragon (12 flights) |
| CRS | 2008 | $1.9 billion | Orbital | Cygnus (8 flights) |
| CCDev | 2010 | $20 million | Sierra Nevada Corp. | Dream Chaser |
| CCDev | 2010 | $18 million | Boeing | CST-100 |
| CCDev | 2010 | $6.7 million | United Launch Alliance | Atlas/Delta human rating |
| CCDev | 2010 | $3.7 million | Blue Origin | Launch abort systems |
| CCDev | 2010 | $1.4 million | Paragon Space | Life support |
| **FY 2011 NASA Authorization**** | | | | |
| Commercial Cargo | FY 2011 | $300 million | TBD | TBD |
| CCDev | FY 2011 | $312 million | TBD in March 2011 | TBD |
| CCDev | FY 2012 | $500 million | TBD | TBD |
| CCDev | FY 2013 | $500 million | TBD | TBD |

** In 2007, NASA terminated the Space Act Agreement with Kistler, due to the company's technical and financial shortfalls. By that time, Kistler already spent about $32 million. The agency reopened bidding later that year for the remaining $175 million, which Orbital won.*

*** From H.R. 5781, the NASA Authorization Act of 2010, signed into law October 11, 2010. The authorization covers FY 2011-FY 2013.[7]*

Table 6. Commercial Orbital Transportation Services (COTS), Commercial Resupply Services (CRS), and Commercial Crew Development (CCDev) contract awards.

destination, such as the ISS or Bigelow's planned space station. Boeing also has a memorandum of agreement with Space Adventures to fly commercial passengers in unused seats to LEO destinations. The vehicle will consist of a conical forward section, similar to an Apollo Command Module but larger, with an aft equipment housing that will be discarded shortly before reentry, exposing the vehicle's heat shield. CST-100 is designed to be reused up to ten times and to be compatible with a variety of expendable launch vehicles, such as the Atlas V, Delta IV or Falcon 9. It will also include a launch escape system.

### Cygnus – Orbital Sciences Corporation

Following NASA's $175 million COTS award to Orbital, the company began developing the Cygnus pressurized cargo transfer vehicle. Orbital's new Taurus II vehicle will lift the Cygnus into space, launching from the Mid-Atlantic Regional Spaceport in Virginia. The first test flights are expected in the first half of 2011, with operational flights expected later that year or in 2012.

The 1,800-kilogram (3,968-pound) Cygnus will comprise a pressurized cargo module and a service module. The service module is based on Orbital's proven STAR satellite bus, used successfully for 31 satellites since 1997. The Pressurized Cargo Module (PCM), developed by Thales Alenia Space and based on the Multi-Purpose Logistics Module used for ISS resupply, will be capable of handling between 2,000 kilograms (4,409 pounds) and 2,700 kilograms (5,952 pounds) depending on mission requirements.[8] Orbital announced that the first three production versions of Cygnus are undergoing pressure tests at Thales' Italy location and that PCM1 will be delivered to Orbital in July 2011 for launch in the spring of 2012.[9] Netherlands-based Dutch Space will build the two solar arrays that will provide 3.5 kW of power to Cygnus.[10] A pressurized passenger version of Cygnus has not been publicly discussed.


Cygnus

A typical Cygnus mission will last about six weeks, with two weeks spent traveling to ISS. After docking at Node 2 of the station, the vehicle will remain berthed for about a month to allow cargo transfers.[11]

A CRS Space Act Agreement signed between NASA and Orbital obligates the company to provide eight Cygnus resupply flights to ISS through 2015.[12]

## Dragon – SpaceX

SpaceX started Dragon with internal funding in 2005 and has used NASA's 2006 COTS award of $278 million to develop its Falcon 9 and Dragon vehicles. Dragon is a pressurized, reusable system designed to carry either cargo or people. It contains a reusable cargo segment called the spacecraft, a nosecone designed to protect the spacecraft's forward docking hatch and collar, and an aft unrecoverable section called the trunk. The spacecraft features a phenolic impregnated carbon ablative shield capable of withstanding reentry temperatures characteristic of missions returning from the Moon or Mars.[13] Two solar arrays are affixed to the trunk, where the life-support system and other components are located. SpaceX also markets the DragonLab™, an unpressurized experiment rack that can be affixed to the trunk.

### *Dragon Cargo Version*

Under COTS, SpaceX is only required to develop a cargo version of Dragon. This version will be capable of carrying 6,000 kilograms (13,228 pounds) of payload to ISS or any point in LEO and transporting up to 3,000 kilograms (6,614 pounds) of material back down to Earth. The Dragon spacecraft will have an available pressurized payload volume of ten cubic meters (245 cubic feet). Dragon will use a reaction control system of 18 Draco thrusters, used for both attitude control and orbital maneuvering. These thrusters tap 1,290 kilograms (2,844 pounds) of propellant, located in a ring of tanks within the aft section of the reusable spacecraft. The spacecraft will also provide a small volume for unpressurized experiments.

Dragon (Cargo)

The trunk will house two solar arrays providing an average of 1,500 watts of power. The standard trunk will have 14 cubic meters (490 cubic feet) of available unpressurized volume, but an optional extension will increase available unpressurized volume to 34 cubic meters. Unrecoverable DragonLabTM experiments will be hosted in the trunk section.[14]

Before berthing with ISS, the nosecone section opens to reveal a Common Berthing Mechanism (CBM) that allows Dragon to connect with the U.S. Harmony module. However, the CBM does not enable docking with any of the four Russian modules, where Soyuz, Progress, and ATV dock. Docking with Russian components requires using an Androgynous Peripheral Attach System (APAS) that allows docking at multiple locations on ISS but adds mass. Nevertheless, the Dragon can be configured with APAS or a Low Impact Docking System, if required. In October 2010, the ISS Multilateral Coordination Board agreed to install standard docking ports throughout the station.[15]

Only the Dragon spacecraft section is reusable. Upon completing a mission, the spacecraft section will disconnect with the unrecoverable trunk section to prepare for reentry. After separation, the Dragon spacecraft reenters the atmosphere, with the assistance of an ablative heat shield. The vehicle is covered with sidewall thermal protection. The cargo version of Dragon will make a parachute-assisted water landing.

SpaceX successfully launched its first Falcon 9 vehicle on June 4, 2010. Although a mock-up of a Dragon vehicle was aboard, that flight was not funded under COTS. Three COTS test flights of Falcon 9 and Dragon are planned for 2011, followed by two ISS resupply flights later that year.

According to its November 2010 filing with the Securities and Exchange Commission, SpaceX raised an additional $50.2 million in new equity financing from 16 investors to help the company continue its work on Dragon.[16] Also in November, FAA/AST issued a commercial reentry license to SpaceX, clearing the way for the company to launch its first test flight in December 2010.[17] This is the first time such a license has been provided. An FAA/AST reentry license is valid for one year from the date of issue.[18]

SpaceX successfully launched a fully functional Dragon cargo vehicle on December 8, 2010, from Cape Canaveral Air Force Station (CCAFS). This was the first test flight under the COTS Space Act Agreement. The vehicle was tested on orbit, including orbital maneuvering, and reentered successfully 3.5 hours after launch, splashing down in the Pacific Ocean.

### *Dragon Passenger Version*

SpaceX did not propose under the initial CCDev competition for crew development of Dragon; however, Paragon did and was awarded $1.4 million to develop an air revitalization system for Dragon and other similar vehicles. SpaceX projects that an investment of $800 million to $1 billion over three years will be required to upgrade Dragon for passenger use. SpaceX hopes to win a contract through NASA's CCDev second round in March 2011, so this funding can be used to upgrade Dragon to carry people.[19]

Externally, the passenger version of Dragon appears similar to the cargo version; both the cargo and passenger versions have windows. The difference lies in the spacecraft section, which will have seats for seven occupants and house the life-support system. The trunk will still be available for unpressurized cargo and experiments.

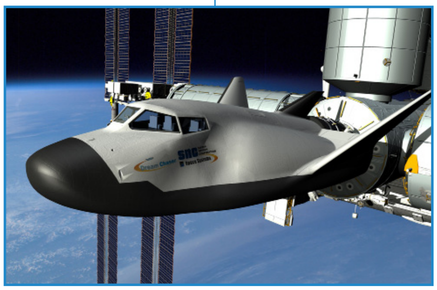
Dragon (Passenger)

The reentry profile for the passenger version of Dragon is the same as for the cargo version. While the first several missions of the crewed Dragon will end with water landings, SpaceX wants to develop retractable landing pads for this version of Dragon. Both landing types, however, will use a parachute to slow the rate of descent.

## Dream Chaser – Sierra Nevada Corporation

In 2010, NASA signed a Space Act Agreement with Sierra Nevada worth $20 million as part of CCDev. Sierra Nevada's subsidiary, SpaceDev, has been developing the vehicle called Dream Chaser, which has a complex heritage.

SpaceDev announced its plan to develop Dream Chaser in 2004, using the HL-20 Personnel Launch System as a basis for design. The HL-20 was a 1988 NASA concept that involved a small, crewed space plane launched aboard an ELV. Following the loss of Space Shuttle Challenger in 1986, NASA pursued plans for a Crew Emergency Return Vehicle (CERV) to support Space Station Freedom. In 1993, Freedom was redesigned and eventually renamed the ISS. The Russian Soyuz became the station's lifeboat as part of an international agreement, effectively ending CERV.[20] In 1989, NASA began to study the HL-20 design as a low-cost alternative to the Space Shuttle for ISS crew transport. The vehicle was designed for launch on an ELV, such as the Titan III. NASA built a mockup in 1991 but chose not to pursue the system. SpaceDev used the abandoned HL-20 plans as a starting point for its Dream Chaser concept. (Dream Chaser will be able to send



Dream Chaser

seven people into LEO. It will be powered by two hybrid engines burning solid-state synthetic rubber and liquid nitrous oxide.)

SpaceDev submitted its Dream Chaser proposal to NASA for the agency's COTS program. Though announced as a finalist in 2006, the company ultimately failed to win a contract. SpaceDev signed a memorandum of understanding in 2007 with United Launch Alliance (ULA) to explore launching Dream Chaser aboard Atlas V vehicles, a concept that remains integral to SpaceDev's plans. Sierra Nevada bought SpaceDev in 2008.

Sierra Nevada gathered a team to develop various components of Dream Chaser. Team members include Adam Works, Aerojet, Boeing Phantom Works, Draper Laboratory, the University of Colorado, and MacDonald Dettwiler Associates (MDA). By February 2010, Sierra Nevada estimated that it spent $10 million of its own money on Dream Chaser and met at least four COTS milestones.[21]

In 2010, NASA signed the $20 million CCDev Space Act Agreement with Sierra Nevada for continuing development of Dream Chaser. Sierra Nevada has used part of this funding to test the company's hybrid liquid-solid engine to power Dream Chaser. The engine passed a milestone three-ignition hot fire test in September 2010, an event certified by NASA. In October 2010, NASA reviewed Sierra Nevada's tooling process used to fabricate aeroshell structures. The agency also certified the tooling in 2010, clearing the way for Sierra Nevada to begin fabricating the Dream Chaser aeroshell in time for testing in December, which was successfully completed.[22]

Also in 2010, Sierra Nevada started exploring Orbital's X-34 RLV demonstrators as testbeds for Dream Chaser. Shortly after the program was cancelled in 2001, two X-34 vehicles were put in storage at Edwards Air Force Base in California. Sierra Nevada is exploring launch options for the demonstrators, including the possibility of deploying from Scaled Composites' WhiteKnightTwo or Orbital's L-1011 used to launch Pegasus XL.[23]

### Sundancer, BA-330, and Space Station Alpha – Bigelow Aerospace

Nevada-based Bigelow Aerospace is developing next-generation expandable space habitats and related technology. The purpose is to construct and deploy a private sector space station with the aim of reducing the cost of space operations. Bigelow Aerospace has launched two prototype spacecraft, Genesis I and Genesis II, on a Russian Dnepr rocket from the Yasny Space and Missile Complex in 2006 and 2007, respectively. Yasny Space and

Missile Complex is located in southern Russia. Bigelow Aerospace used these missions to validate their spacecraft designs, specifically the idea of expandable space habitats. Bigelow Aerospace is now in the process of developing full-scale spacecraft that will support a human presence on orbit.

The first of these modules currently in development is the Sundancer, an expandable habitat to sustain a crew of three. The habitat has a usable volume of 180 cubic meters (6,200 cubic feet). Terrestrial and on-orbit testing has demonstrated that the multi-layer nature of the inflatable hull more effectively protects against radiation and orbital debris than the type of metal design employed by ISS modules. A combination of solar arrays and batteries provides electrical power for the Sundancer. The module will also have an independent avionics system to support navigation and orbital maneuvering. The Sundancer will be outfitted with an Environmental Control and Life Support System (ECLSS) that will include a lavatory and miscellaneous hygiene facilities. Finally, the Sundancer will feature large windows with ultraviolet screening.[24]

The company is also developing the BA-330 that will offer nearly twice the usable volume of the Sundancer. The BA-330 will be capable of sustaining a crew of six for long-duration missions. The first Bigelow Aerospace Orbital Space Complex (Space Station Alpha) will comprise two Sundancer habitats, a node-bus combination, and a BA-330 module. This station will be able to support a crew of twelve. The Bigelow station will support a broad variety of scientific and commercial activities, with a potential focus on microgravity research and development.[25]

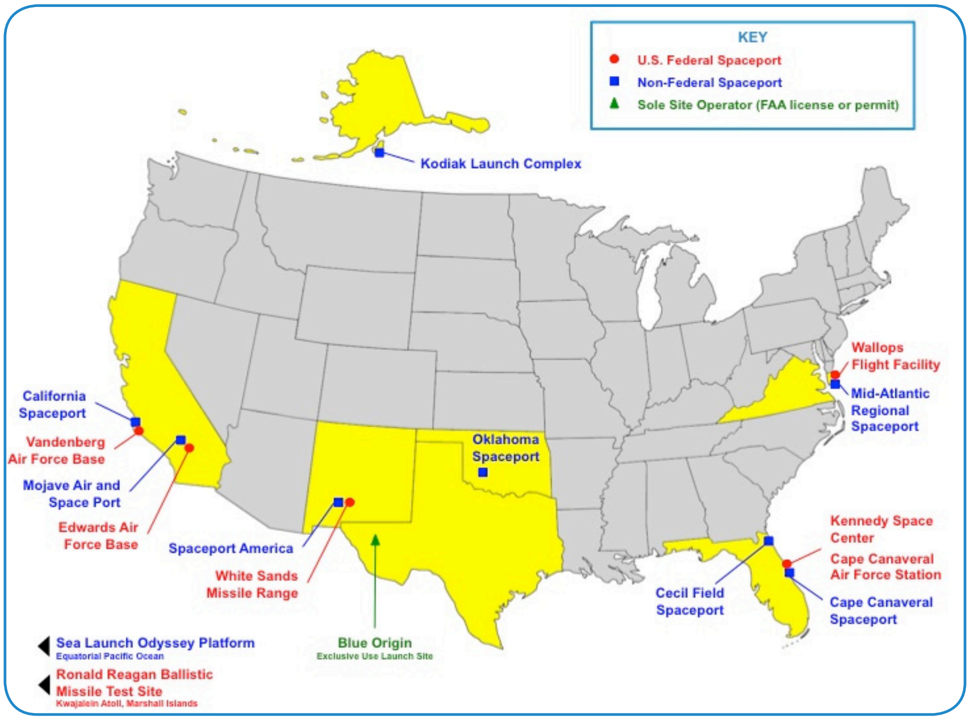

Sundancer

To transport crew to the station, Bigelow Aerospace became a member of the Boeing CCDev team. Bigelow is actively supporting Boeing's efforts to develop the CST-100 reusable in-space crew transport, profiled earlier in this report.[26]

Moreover, Bigelow Aerospace has begun preliminary international outreach efforts. The company has already signed agreements with national space agencies, companies, and governmental entities in the Netherlands, Sweden, Singapore, Japan, the United Kingdom, and New South Wales, Australia.[27]

Bigelow Aerospace has initiated a substantial expansion to its North Las Vegas manufacturing plant, adding 17,187 square meters (185,000 square feet). Also in 2010, Bigelow Aerospace and partner Orbital Technologies Corporation began testing an ECLSS using human participants (profiled in the next section); earlier tests were simulated.[28]

# SPACEPORTS




Spaceports are sites dedicated to launching orbital or suborbital vehicles into space. These sites often also provide the capability to integrate launch vehicle components, to integrate vehicles with payloads, to fuel and maintain vehicles, and to launch vehicles. From the spaceport, an orbital launch vehicle travels over an area called the launch range, which typically includes tracking and telemetry assets. These range assets monitor the vehicle's performance until it safely delivers a payload into orbit or returns to Earth. Tracking and telemetry assets may also facilitate recovery of reusable stages.

The FAA licenses the operation of commercial spaceports in the United States, and by 2010 the FAA issued eight licenses (Table 7). These licenses may be renewed every five years. NASA's Kennedy Space Center (KSC) and the Air Force's Cape Canaveral Air Force Station (CCAFS) are examples of launch facilities that do not require an FAA license, because they are operated by the federal government.

Some federal launch facilities, including CCAFS, are available to commercial launch providers using FAA-licensed vehicles. Zero Gravity Corporation has used KSC's Space Shuttle Landing Facility for commercial microgravity flights, and KSC may be used for commercial reusable launch vehicles (RLVs) in the future.[1]

In most cases, spaceports facilitate vertical launches, which means that vehicles lift off from pads, rather than from runways. These vehicles may be expendable or reusable. They may be integrated vertically (stages stacked on top of one another with a payload added on top) or horizontally (stages and payload stacked using rolling cradles, then erected once integration is complete). Typical features of a launch pad include a reinforced concrete pad, blast deflectors, servicing towers or gantries, and lightning rods. A water tower may also be nearby, supporting fire or sound suppression.

Four FAA-licensed spaceports, Cecil Field Spaceport, Mojave Air and Space Port, Oklahoma Spaceport, and Spaceport America, also feature runways for launch vehicles that take off or land horizontally, similar to airplanes.

| Spaceport | Operator | State | License First Issued | Expires |
|---|---|---|---|---|
| California Spaceport | Spaceport Systems International | California | 1996 | September 18, 2011 |
| Cape Canaveral Spaceport | Space Florida | Florida | 1999* | June 30, 2015 |
| Cecil Field Spaceport | Jacksonville Aviation Authority | Florida | 2010 | January 10, 2015 |
| Kodiak Launch Complex | Alaska Aerospace Development Corporation | Alaska | 1998 | September 24, 2013 |
| Mid-Atlantic Regional Spaceport | Virgnia Commercial Space Flight Authority | Virginia | 1997 | December 18, 2012 |
| Mojave Air and Space Port | East Kern Airport District | California | 2004 | June 16, 2014 |
| Oklahoma Spaceport | Oklahoma Space Industry Development Authority | Oklahoma | 2006 | June 11, 2011 |
| Spaceport America | New Mexico Spaceport Authority | New Mexico | 2008 | December 15, 2013 |

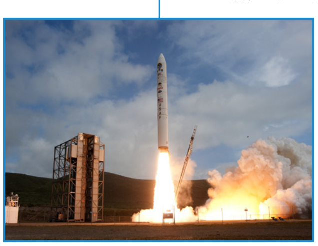
** Issued to predecessor organization, Spaceport Florida Authority.*

Table 7: FAA-licensed spaceports.

## FAA-Licensed Commercial Spaceports

### California Spaceport, California

Spaceport Systems International (SSI), established in 1993, operates California Spaceport. In 1996, the FAA issued the first Commercial Space Launch Site Operator's License to this spaceport. SSI received this license one year after signing a 25-year lease with the Air Force to provide commercial launch services from a 100-acre plot located on Vandenberg Air Force Base (VAFB). The lease also included a payload processing facility.



California Spaceport

California Spaceport is home to the Commercial Launch Facility (CLF). The CLF is located at Space Launch Complex-8 (SLC-8), which was completed in 1999. The CLF consists of a pad and support facilities. The launch control center and administrative areas are located nearby at SLC-6. SLC-8 is configured for launch vehicles using solid propellants only, such as the Minotaur IV and vehicles using the Castor 120 motors. The spaceport is available for payloads destined for low Earth orbit (LEO), specifically polar orbits.[2]

| California Spaceport | |
|---|---|
| Location | Vandenberg AFB, California |
| Owner/ Operator | Spaceport Systems International (SSI) |
| License Status | Active FAA Launch Site Operator License |
| Description | Operating through a 25-year lease since 1995, California Spaceport offers commercial launch and payload processing, and supports a variety of mission profiles to low-polar-orbit inclinations. |
| Infrastructure | Launch pads, runways, payload processing facilities, telemetry, and tracking equipment. |

Since January 2000, SLC-8 has had seven orbital launches, all successful. The first launch of Orbital Science Corporation's (Orbital) Minotaur IV from SLC-8 was on April 22, 2010, carrying Hypersonic Test Vehicle-2A for the Department of Defense (DoD). On September 25, 2010, another Minotaur IV successfully launched the Space-Based Surveillance System from SLC-8.[3]

## Cape Canaveral Spaceport, Florida

Space Florida was established in 2006 as Florida's aerospace development organization and to coordinate space activities within the state. Space Florida is responsible for the Cape Canaveral Spaceport, co-located with CCAFS and KSC.

Cape Canaveral Spaceport (LC-36)

Cape Canaveral Spaceport consists of two orbital launch complexes (LC-36 and LC-46) and a Space Life Sciences Laboratory. It also supports activity at SLC-40, which SpaceX uses for its Falcon 9 launches. Finally, Space Florida owns and manages an RLV hangar located at the Space Shuttle Landing Facility. The RLV hangar and runway is available for limited commercial use, such as the suborbital flight training conducted by Starfighter Aerospace.

| Cape Canaveral Spaceport | |
|---|---|
| Location | Cape Canaveral, Florida |
| Owner/ Operator | Space Florida |
| License Status | Active FAA Launch Site Operator License |
| Description | Launch sites for vertical take-off commercial launch vehicles. Space Florida received $4 million in direct state appropriations to support its operations for fiscal year 2009. |
| Infrastructure | Three commercial orbital launch complexes with a remote control center, one suborbital launch complex with two pads and a blockhouse, an off-site solid rocket motor storage facility that includes heavy rail access, a 27-m (90-ft) high bay with overhead cranes, a 5,200-square-meter (50,000-square-foot) RLV support hangar adjacent to the KSC Shuttle Landing Facility runway, and a 9,290-square-meter (100,000-square-foot) Space Life Sciences Lab at KSC. |

In July 2010, the FAA approved a Commercial Space Launch Site Operator's License for LC-46, allowing Space Florida to explore commercial use of the complex.[4] This event followed DoD's approval of an Explosive Site Plan for the complex in May 2010 and an award of a Real Property License from the Air Force in February 2010. Space Florida, using a $500,000 grant from the State of Florida, is refurbishing LC-46, which has not been used for launches since 1999.[5] The site will support launches of Lockheed Martin/ATK's new Athena Ic and IIc and Orbital's Minotaur and Taurus.[6]

Space Florida is also overseeing the reconfiguration of

LC-36, which has not been used since 2005, to handle a variety of small- to medium-class vehicles, including the Falcon 1 and Taurus II. The FAA has not yet approved a license for LC-36, but the Real Property License from the Air Force covers LC-36. Space Florida is also configuring LC-36 as a technology demonstration site for cryogenic testing and rocket engine static tests and as a launch site for suborbital vehicles, such as those planned by Masten Space Systems.

Space Florida also operates LC-47, a small site used to launch sounding rockets. The pad was built in 1984 to support NASA-managed weather research and Air Force upper-altitude winds measurement.

Space Florida is currently evaluating and analyzing the possibility of commercial space transportation providers using future vacated facilities from the Delta II and Space Shuttle Programs.[7]

## Cecil Field Spaceport, Florida

The FAA issued Jacksonville Aviation Authority (JAA) a Space Launch Site Operator's License in January 2010.[8] The license authorizes use of Cecil Field Spaceport for horizontal take off and landings of suborbital launch vehicles. The U.S. Navy once operated Cecil Field as an airfield, which was closed in 1993 and transferred to the City of Jacksonville in 1999.[9]

Cecil Field Spaceport

The spaceport is located about 24 kilometers (15 miles) from Jacksonville and features a 3,810-meter (12,500-foot) runway and three shorter runways. The spaceport shares assets with Cecil Field Airport, which services military and civil aircraft and general aviation customers. Boeing and Northrop Grumman operate several maintenance and overhaul facilities at Cecil Field for the DoD.

| Cecil Field Spaceport | |
|---|---|
| Location | Jacksonville, Florida |
| Owner/ Operator | Jacksonville Aviation Authority (JAA) |
| License Status | Active FAA Launch Site Operator License |
| Description | Commercial spaceport supporting horizontal launch for commercial, government, and non-profit users. Cecil Field is a retired Naval Air Station. |
| Infrastructure | Four runways, 175 buildings, 8 aircraft hangars, an active air traffic control tower, warehouse, industrial, office, general use, and support facilities. |

During 2009, Cecil Field received several visits from Virgin CEO Sir Richard Branson of Virgin Group. His visits included discussions with spaceport managers about the possibility of supporting Virgin Galactic flights. Virgin Galactic is already an anchor tenant at Spaceport America in New Mexico.[10]

The FAA awarded $105,000 to JAA, as part of the FAA's Space Transportation Infrastructure Matching Grants program in 2010. JAA will use the money to develop a Spaceport Master Plan for Cecil Field.[11]

### Kodiak Launch Complex, Alaska

Kodiak Launch Complex

The FAA licensed the Kodiak Launch Complex on Kodiak Island, Alaska in 1998. This is the first FAA-licensed spaceport that is not co-located on a federally controlled launch site. Kodiak has one launch pad (LP-1) that can launch intermediate-class payloads to LEO or a highly elliptical polar orbit. The complex also has a suborbital launch pad (LP-2) used for missile testing. LP-1 features a flame trench rated for up to 500 metric tons of thrust. The complex features a launch control and management center, a payload processing facility, an integration and processing facility, a spacecraft assemblies transfer facility, and a service structure at the launch pad. All facilities at Kodiak allow for enclosed processing of medium- to small-class launch vehicles.

Fifteen launches have been conducted at Kodiak since it opened in 1991.[12] Only two have been orbital: Kodiak Star was a joint mission conducted by NASA and the DoD and was successfully launched in 2001. In November 2010, the spaceport conducted its second orbital launch, when a Minotaur IV carried seven payloads for NASA and the Air Force's Space Test Program.

In 2010, Lockheed Martin announced the revival of the Athena launch vehicle family and highlighted Kodiak Launch Complex as a possible launch site for the vehicles.[10] In October 2010, the FAA awarded $227,195 to the Alaska Aerospace Development Corporation, as part of the Space Transportation Infrastructure Matching Grant Program. The corporation will use the money to build a rocket motor storage facility.[13]

| Kodiak Launch Complex | |
|---|---|
| Location | Kodiak Island, Alaska |
| Owner/ Operator | Alaska Aerospace Development Corporation |
| License Status | Active FAA Launch Site Operator License |
| Description | Kodiak Launch Complex was the first commercial launch site located outside of a federal facility. Launch site for military, government, and commercial telecommunications, remote sensing, and space science payloads. |
| Infrastructure | Launch Control Center with integral Launch Operations Control Center, Weather Forecast Office, and Tech Control Center; Maintenance and Support Facility; Instrumentation Field, Payload Processing Facility; Integration Processing (rocket assembly) Facility; mobile Spacecraft Assemblies Transfer Facility; two launch pads with two more in design; and a Rocket Motor Storage Facility. |

### Mid-Atlantic Regional Spaceport, Virginia

The Mid-Atlantic Regional Spaceport (MARS) has two FAA-licensed launch pads. The spaceport also features rail launchers for sounding rockets, vehicle and payload storage, processing facilities, a horizontal vehicle assembly facility, a hypergolic fueling facility, and a large capacity liquid fueling facility for expendable launch vehicles (ELVs). In addition, landing and payload recovery capabilities and a co-located airport support RLVs. Flexible mission support allows MARS to accommodate scheduling for commercial, scientific, and government customers.[14]

In December 1997, the FAA issued the Virginia Commercial Space Flight Authority a Space Launch Site Operator's License for operating a commercial spaceport co-located at the NASA Wallops Flight Facility (WFF). On the mid-Atlantic coast, MARS offers optimal orbital inclinations between 38 degrees and 60 degrees. Other inclinations, including sun-synchronous orbit, can be accessed on a case-by-case basis. MARS operates two launch pads (0-A and 0-B).

| | Mid-Atlantic Regional Spaceport |
|---|---|
| Location | Wallops Island, Virginia |
| Owner/ Operator | Virginia Commercial Space Flight Authority |
| License Status | Active FAA Launch Site Operator License |
| Description | Commercial spaceport co-located with NASA's Wallops Flight Facility that supports vertical and horizontal space launch for commercial, government, and non-profit users. |
| Infrastructure | Two orbital launch pads, multiple suborbital launching rails, payload processing and integration facilities, vehicle storage and assembly buildings, class-100,000 clean room, mobile liquid fueling capability, on-site and down range telemetry and tracking, and payload recovery capability. |

Since 2007, the State of Virginia has passed two bills to boost the presence of commercial space transportation in the state. The first, the Virginia Space Liability and Immunity Act in 2007, became effective July 1997. The law seeks to lower human spaceflight insurance liability costs for commercial firms launching from MARS. Effective July 1, 2008, the Zero G Zero Tax Act of 2008 will exempt business earnings related to human spaceflight training or launches from MARS from state income taxes.[15] MARS also offers customers both enterprise and foreign trade zone tax incentives.

Using a Minotaur I vehicle, MARS launched TacSat-2 in December 2006, the spaceport's first orbital launch. NFIRE was launched in April 2007 and TacSat-3 in May 2009, both on Minotaur I vehicles. Currently, MARS has 11 launches on its manifest through 2015, including its first robotic Moon mission for NASA. No launches from MARS occurred in 2010.

In preparation for launches of the larger Minotaur IV and Minotaur V vehicles, MARS completed extensive upgrades to Pad 0-B in 2010. These upgrades are designed to facilitate vehicle break-over (a process that erects a launch vehicle from a horizontal to vertical position) and stacking. The upgrades also include expanding and enhancing the gantry for improved thermal and environmental protection, larger work areas around the vehicle and payload, and operable roof doors to expedite stage-stacking operations. The Air Force will launch the ORS-1 mission using a Minotaur I from Pad 0-B in early 2011. NASA will launch the Lunar Atmosphere Dust Environment Explorer mission aboard the first Minotaur V from Pad 0-B in early 2013.

Pad 0-A will be used for Orbital's Taurus II launch vehicle and other mid-class launch vehicles. Upgrading this pad, which will cost an estimated \$100 million, is planned for completion during the first quarter of 2011. Virginia provided \$26 million in bond financing for Pad 0-A expansion. This expansion includes a large capacity liquid fueling storage and transfer facility, a dual-bay horizontal integration facility, a payload and cargo processing facility, transportation infrastructure upgrades, and construction of a larger launch pad. In mid-2011, Orbital's first International Space Station (ISS)-bound transportation demonstration flight will launch from this pad on the Taurus II.

MARS (Pad 0-A)

In 2008, Orbital signed a $1.9 billion Commercial Resupply Service (CRS) contract with NASA. This contract obligates Orbital to provide eight ISS cargo resupply flights between 2011 and 2015. These flights are planned for launch from MARS Pad 0-A and are included in the fifteen in the MARS manifest.

Mojave Air and Space Port

**Mojave Air and Space Port, California**

Mojave Air and Space Port is home to Masten, which designs, builds, and launches suborbital reusable vertical take-off and landing vehicles. The company builds its vehicles in a 557 square-meter (6,000 square-foot) production facility and conducts launches from an 18,581 square-meter (200,000 square-foot) site located at the spaceport. The site is currently used for vehicle testing. The FAA has not yet issued a license for commercial vertical launches.

In August 2010, Masten announced a contract award by NASA in support of the agency's Commercial Reusable Suborbital Research (CRuSR) program. The initial contract calls for four flights of test payloads on the company's Xaero vehicle, beginning in 2011.[16]

On June 17, 2004, the FAA granted East Kern Airport District a Space Launch Site Operator's License for horizontal take off at Mojave Air and Space Port. The spaceport has become a site for small companies designing, building, and testing small RLVs, including Scaled Composites, XCOR Aerospace, Masten, and Interorbital Systems.

The spaceport operates three runways, and the longest is 3,810 meters (12,500 feet).

In October 2010, the FAA awarded the East Kern Airport District $125,000, as part of the Space Transportation Infrastructure Matching Grants program. The East Kern Airport District will use the money to purchase an emergency response vehicle.[17]

In November 2010, The Spaceship Company broke ground on a new 6,317-square-meter (68,000-square-

| Mojave Air and Space Port | |
|---|---|
| Location | Mojave, California |
| Owner/ Operator | East Kern Airport District (EKAD) |
| License Status | Active FAA Launch Site Operator License |
| Description | An airport used for flight testing, space industry development, and aircraft heavy maintenance and storage. |
| Infrastructure | Air traffic control tower, three runways, rotor test stand, engineering facilities, and high bay building. Easy access to restricted airspace. Space zoned specifically for rocket motor development and testing. |

foot) manufacturing facility at the spaceport. The clear-span hanger will feature offices, manufacturing, and test facilities. The hangar is large enough to allow production of two WhiteKnightTwo aircraft and at least two SpaceShipTwo vehicles at one time.[18]

### Oklahoma Spaceport, Oklahoma

Oklahoma Spaceport

The FAA issued a Space Launch Site Operator's License to the Oklahoma Space Industry Development Authority (OSIDA) in June 2009 for operation of Oklahoma Spaceport. The spaceport is licensed as a horizontal take-off and landing site for RLVs, with a flight corridor for space operations within the national airspace system. Air traffic is also authorized to use Oklahoma Spaceport.

Oklahoma Spaceport features a 4,116-meter (13,503-foot) runway with 304-meter (1,000-foot) overruns, one of the longest runways in North America. A large parking apron, four large hangars, and a 4,645-square-meter (50,000-square-foot) manufacturing facility are available. A medical facility and crash unit are also on site.

In February 2010, the Oklahoma Legislature narrowly passed a bill to continue funding OSIDA with an FY 2010 budget of $424,289. (The Oklahoma fiscal year begins on July 1.) The legislature reduced OSIDA staff from five to three.

| | Oklahoma Spaceport |
|---|---|
| Location | Washita County, Oklahoma |
| Owner/ Operator | Oklahoma Space Industry Development Authority (OSIDA) |
| License Status | Active FAA Launch Site Operator License |
| Description | Provides launch and support services for horizontally launched suborbital RLVs. |
| Infrastructure | A 4,100-meter (13,500-foot) runway; 5,200-square meter (50,000-square-foot) manufacturing facility; 2,800-square-meter (30,000-square-foot) maintenance and painting hangar; 6 commercial aircraft hangars, including a 2,800-square-meter (30,000-square-foot) maintenance and paint facility; 39 hectare (96 acre) of concrete ramp, control tower, crash and rescue facility; and 435 square kilometers (168 square miles) of land available for further construction. |

By March 2010, using $380,000 in FAA grants, OSIDA installed Precision Approach Path Indicator systems for the spaceport's two runways and replaced the old rotating airport beacon. The FAA tested flight approaches for both runways and authorized the spaceport to issue terminal weather forecasts. In addition, the perimeter fence was upgraded.[19]

In July 2010, Rocketplane, which was based at Oklahoma Spaceport, filed for bankruptcy, a potential setback for OSIDA.[20]

### Spaceport America, New Mexico

Spaceport America is the world's first purpose-built commercial spaceport. It is currently under construction and will be managed by the New Mexico Spaceport Authority (NMSA). Spaceport America is located in


Spaceport America

Sierra County, near the city of Truth or Consequences, New Mexico. The spaceport received its Space Launch Site Operator's License for vertical launch operations from the FAA in 2008.[21]

UP Aerospace is the only provider of commercial, vertically launched suborbital missions at Spaceport America. The company operates a single pad that features a rail system for vehicle transportation and vertical launch tower. These are supported by a payload processing facility, a launch control center, and a vehicle assembly building. The complex can handle vehicles with a mass of 1,134 kilograms (2,500 pounds) or less. A typical suborbital launch will end with a parachute-assisted landing and recovery at White Sands Missile Range to the east. UP Aerospace has conducted four suborbital launches from the site since 2006. The spaceport has also hosted three suborbital vehicle tests by Lockheed Martin and one by Moog-FTS.

In September 2010, Armadillo Aerospace announced its plan to conduct test operations at Spaceport America to support two NASA-funded CRuSR vehicles.[22] Both flights will be conducted with an FAA Amateur Rocket Class III waiver, since the flights will only reach an altitude of about 15 kilometers (nine miles). An additional flight is planned for an altitude of 40 kilometers (25 miles), which will require an FAA license or permit.[23]

The FAA granted NMSA a Space Launch Site Operator's License on December 18, 2008, for operation of Spaceport America. Virgin Galactic, the anchor tenant, signed a 20-year lease agreement immediately after issuance of the license.[24] Construction of the spaceport's main terminal building, training facility, and mission control center has progressed steadily since 2009, with completion expected in 2011. The 3,000-meter (10,000-foot) runway was dedicated on October 22, 2010, and renamed the Governor Bill Richardson Spaceway in honor of the New Mexico governor.[25]

The main terminal hangar will able to house two Virgin Galactic WhiteKnightTwo aircraft and five SpaceShipTwo spacecraft. Test flights of these vehicles began in March 2010 and launched from Mojave Air and Space Port. Commercial flights will launch from Spaceport America after successful completion of flight tests and licensing of the space launch system by the FAA.

In September 2010, the FAA awarded the NMSA $43,000 to provide an Automated Weather Observing

| Spaceport America | |
|---|---|
| Location | Upham, New Mexico |
| Owner/ Operator | New Mexico Spaceport Authority (NMSA) |
| License Status | Active FAA Launch Site Operator License |
| Description | A commercial spaceport in development that will support vertical and horizontal space launch. |
| Infrastructure | Current infrastructure includes a runway, vertical launch pad, weather station, rocket motor storage facilities, and trailers. Planned infrastructure includes a central control facility, maintenance and integration facility, launch and recovery complex, and a cryogenic plant. |

System (AWOS), as part of the FAA's Space Transportation Infrastructure Matching Grant Program.[26] AWOS is a modular sensor suite that will capture real-time weather data to support airport and spaceport operations.

## Federal Spaceports Providing Commercial Access

| Spaceport | Operator | State | Available to FAA-Licensed Launch Vehicles |
|---|---|---|---|
| Cape Canaveral Air Force Station | USAF | Florida | SLC-41 (Atlas V)<br>SLC-37B (Delta IV)<br>SLC-40 (Falcon 9) |
| Edwards Air Force Base | USAF | California | No |
| Kennedy Space Center | NASA | Florida | No* |
| Poker Flat Research Range | University of Alaska Fairbanks Geophysical Institute | Alaska | Five pads available for suborbital launches |
| Vandenberg Air Force Base | USAF | California | SLC-3E (Atlas V)<br>SLC-2 (Delta II)<br>SLC-6 (Delta IV)<br>SLC-4E (Falcon 1)<br>LC-576E (Taurus) |
| Wallops Flight Facility | NASA | Virginia | Six pads available for suborbital launches |
| White Sands Missile Range | USA | New Mexico | No |

** May be used in the future for commercial RLV flights.*

Table 8: Federal spaceports.

### Cape Canaveral Air Force Station, Florida

CCAFS (LC-41)

Cape Canaveral Air Force Station (CCAFS) is located east of Florida's Merritt Island. It is operated by the Air Force Space Command's 45th Space Wing, which is headquartered at Patrick Air Force Base and commanded by the 14th Air Force. The 45th Space Wing is also responsible for managing the Eastern Range. The Eastern Range supports all orbital and suborbital launches from the eastern coast of the United States. Launch operations are conducted by a team of contractors and military personnel, but the range is entirely controlled by the Air Force.[27]

CCAFS is home to 34 launch complexes, though only six remain operational and available for commercial use. LC-36, LC-46, LC-40, and LC-47 were described earlier in this section for Cape Canaveral Spaceport. United Launch Alliance (ULA) and Boeing Launch Services (BLS) use LC-17, which consists of two pads, for the Delta II vehicle. LC-17 has been used since 1957. LC-17A was shut down in 2009, and LC-17B will likely become inactive after a planned final Delta II flight in 2011.

| Cape Canaveral AFS | |
|---|---|
| Location | Cape Canaveral, Florida |
| Owner/ Operator | United States Air Force |
| License Status | N/A |
| Description | CCAFS conducts launch operations and provides range support for military, civil, and commercial launches. Home of the 45th Space Wing, which oversees the Eastern Range. |
| Infrastructure | Telemetry and tracking facilities, jet- and Shuttle-capable runways, reentry corridors, operations control center, movable hangar, fuel tanks, water towers, and launch pads. |

ULA and BLS use LC-37 to launch Delta IV vehicles. This complex has two pads, and one has never been used. NASA built this complex in 1964 to support its Saturn I and Saturn IB vehicles. The complex was deactivated by the Air Force in 1972, but was later refurbished by Boeing to support Delta IV vehicles. The first launch of a Delta IV from LC-37 was in 2002.

ULA and Lockheed Martin Commercial Launch Services use LC-41 to launch the Atlas V. This complex features one pad, which was originally built in 1965 to support Titan III and Titan IV launch campaigns. The Atlas V has been launched from LC-41 since 2002.

SpaceX uses LC-40 to launch its new Falcon 9 vehicle. This complex was used by the Air Force until 2005 for Titan III and Titan IV vehicles. The June 4, 2010, inaugural launch of Falcon 9 took place from this complex.

## Ronald Reagan Ballistic Missile Defense Test Site, Kwajalein Atoll

| Reagan Test Site | |
|---|---|
| Location | Kwajalein Atoll, Pacific Ocean |
| Owner/ Operator | United States Army Space and Missile Defense Command |
| License Status | N/A |
| Description | The Reagan Test Site (RTS) conducts 24/7 space control operations to provide space situational awareness and protect key space assets supporting U.S. Central Command, U.S. Pacific Command, and U.S. Northern Command. Launch facilities support space launch as well as scientific, tactical, and strategic missile launches. |
| Infrastructure | Telemetry, radars, and optical tracking systems, ship-based telemetry/safety system, mission control facility, wideband connectivity with the continental U.S., multiple safety systems and launch facilities, runway, warehouse and industrial use space, user and engineering office space. |

Kwajalein Atoll consists of just under 100 islands, and the largest is Kwajalein. The Army operates several missile launch sites throughout the atoll. Most test launches support ballistic missile defense programs. The site is attractive not only for its isolation, but also because of its equatorial location, ideal for launches to geosynchronous Earth orbit.

SpaceX selected Omelek, an island north of Kwajalein, for equatorial launches of its Falcon 1 vehicle. The island was used by the U.S. military for many years to conduct small rocket launches, until operations shifted to other islands in the atoll in 1996. The FAA required SpaceX to complete an Environmental Impact Study (EIS) before refurbishing Omelek facilities to accept Falcon 1 vehicles. The EIS was completed in 2004, and no major issues were raised,[28] so SpaceX proceeded with five launches of Falcon 1 between 2006 and 2009. SpaceX expects to continue launching Falcon 1 from Omelek Island. SpaceX also plans to launch the larger Falcon 9 from this site.[29]

## Vandenberg Air Force Base, California

Vandenberg Air Force Base (VAFB) is located on the California coast in Santa Barbara County. The 30$^{th}$ Space Wing, a unit commanded by the 14$^{th}$ Air

| Vandenberg AFB | |
|---|---|
| Location | Vandenberg AFB, California |
| Owner/ Operator | United States Air Force |
| License Status | N/A |
| Description | Headquarters of the 30th Space Wing and the Air Force Space Command organizations responsible for all DoD space and ballistic activities for the West Coast. |
| Infrastructure | Launch pads, vehicle assembly, and processing buildings, payload processing facilities, telemetry and tracking facilities, control center, engineering, user office space, and Shuttle-capable runways. |

Force, manages launches from VAFB. The wing is also responsible for the Western Range, which monitors all orbital and suborbital flights from the western coast of the United States. Launches from VAFB are generally destined for polar orbits and typically launch remote sensing payloads for the National Reconnaissance Office, NASA, and commercial customers.


VAFB (SLC-2)

There are six active space launch complexes at VAFB: SLC-2, SLC-3, SLC-4, SLC-6, SLC-8, and LC-576E. SLC-8 has already been described in this section under California Spaceport. SLC-2, operational since 1966, consists of two pads (SLC-2E, decommissioned in 1972, and SLC-2W) and is currently used to support Delta II launch campaigns. SLC-3 also consists of two pads, but SLC-3E was used for the discontinued Atlas IIAS vehicle and has not been used since 2003. SpaceX used SLC-3W for its Falcon 1 vehicle, but the company has decided to shift Falcon 1 operations to SLC-4 beginning in 2012.

The Air Force built SLC-6 in the early 1960s to support the Manned Orbiting Laboratory program, which was cancelled in 1969. The Air Force, together with NASA, refurbished this complex in the 1970s in anticipation of the Space Shuttle program, but, due to cost overruns and other considerations, the Shuttle never flew from VAFB. SLC-6 remained inactive until the late 1990s, when refurbishment to support Delta IV launch vehicles began. Beginning in 2006, the Air Force has successfully launched two Delta IV vehicles from SLC-6.

LC-576 is a launch complex consisting of 11 individual pads, only one of which is active; LC-576E. LC-576E is used for Taurus launches. The next Taurus launch will carry NASA's Glory spacecraft, an Earth Sciences mission, in early 2011. Eight Taurus launches have launched from the pad since 1994.


Wallops Flight Facility

**Wallops Flight Facility, Virginia**

NASA's WFF is the primary provider of NASA's science suborbital and small orbital flight programs. Annually, WFF conducts approximately thirty sounding rocket missions from this and other sites worldwide. It also conducts about twenty balloon missions per year and several hundred hours of piloted and unpiloted aircraft missions.

In addition to supporting these programs, WFF manages the Wallops

| Wallops Flight Facility | |
|---|---|
| Location | Wallops Island, Virginia |
| Owner/ Operator | National Aeronautics and Space Administration |
| License Status | N/A |
| Description | A federally funded research, development, and testing facility supporting vertical launch and aircraft based launch. |
| Infrastructure | Runway, telemetry and tracking facilities, integration & testing facilities, Class-100,000 clean room for spacecraft. Co-located with Mid-Atlantic Regional Spaceport (MARS). |

Research Range, consisting of the launch range, mobile range, and research airport. These facilities support research and development as well as operational mission capabilities. Range services typically include integration and test facilities, tracking and data services, range safety, engineering support, launchers, and logistical services.

WFF's Research Range has conducted more than 16,000 launches over its 65-year history and annually conducts several hundred missions, including approximately 20 rocket launches. The WFF launch range includes five general launch areas comprising multiple suborbital rocket pads, several special purpose launch pads, and two launch areas provided via a Space Act Agreement to the Virginia Commercial Space Flight Authority (VCSFA) containing ELV complexes. Through NASA's relationship with VCSFA, the two organizations partner to provide an integrated launch service for larger range missions to both government and commercial customers.[30]

## Proposed and Inactive U.S. Spaceports

Several state governments and local communities have proposed establishing commercial spaceports. In the cases listed in Table 8, little to no evidence of recent progress on the spaceports was identified.

| Spaceport | Operator | State | Status |
|---|---|---|---|
| Chugwater Spaceport | Frontier Astronautics | Wyoming | Inactive – No further action on this spaceport proposal since 2007. |
| South Texas Spaceport | Willacy County Development Corporation for Spaceport Facilities | Texas | Inactive – The 13-county South Texas Spaceport Consortium, which was established to pursue spaceport funding, disbanded in 2006. No further development since then. |
| Spaceport Alabama | Spaceport Alabama Program Office at Jacksonville State University | Alabama | Inactive – No legislative activity has taken place, and the Alabama Commission on Aerospace, which pursued the proposal, appears inactive. |
| Spaceport Hawaii | Hawaiian Office of Aerospace Development | Hawaii | Proposed – Legislature passed funding bill to support an application to the FAA for a spaceport license. It became law without the governor's signature on July 16, 2009. No further developments. [31] |
| Spaceport Indiana | Space Port Indiana, Inc. | Indiana | Proposed – During 2010, activity at Spaceport Indiana was limited to education and hobby rocketry. |
| Spaceport Sheboygan | City of Sheboygan | Wisconsin | Proposed – Wisconsin Aerospace Authority was established in 2006 in part to pursue a suborbital launch site. WAA has not yet applied for an FAA license. [32] |
| Spaceport Washington | Port of Moses Lake | Washington | Inactive – No further action on this spaceport proposal since 2007. |
| West Texas Spaceport | Pecos County/West Texas Spaceport Development Corporation | Texas | Inactive – Spaceport would build upon test site infrastructure established for NASA/USAF rocket testing and by Blue Origin. A Pecos County West Texas Spaceport Development Corporation seat remains active on the County Board. |

Table 9: Proposed and inactive U.S. commercial spaceports.

# ENABLING TECHNOLOGIES

This chapter discusses new technologies that directly enable launch vehicles. Industry participants develop new technologies to solve system challenges, support government projects, and provide a competitive edge. Successful new technologies for the commercial space industry are often designed for a specific system, but they can expand in use for a range of future systems.

This chapter identifies technologies in development that will significantly improve the performance of commercially available expendable launch vehicles (ELVs), reusable launch vehicles (RLVs), and in-space transportation vehicles. These technologies are grouped into five primary functional areas: guidance, navigation, and control (GNC); life support; propulsion; structures; and space suits. The highlighted technologies are in development and have achieved a milestone in 2010, indicating increased technology maturity. Other technology areas such as ground segment, power, and thermal control are not profiled in this report, because no enabling technologies were identified that achieved a milestone this year.

The following technologies are not an exhaustive list and are solely based on open-source research, primarily press releases. The FAA does not promote individual companies or technologies with this list, but provides examples of ongoing developments that support the commercial space industry.

## Guidance, Navigation, and Control

Spacecraft, both RLV and ELV, require avionics and hardware for GNC. Primary vehicle developers and second-tier contractors are developing new systems to support GNC of future commercial spacecraft.

### Atlas V/Delta IV Emergency Detection System – United Launch Alliance, Pratt & Whitney Rocketdyne, National AeroSpace Training and Research Center, and Special Aerospace Services

The Emergency Detection System (EDS) supports converting the Atlas V and Delta IV launch vehicles into crew transportation systems.[1] This system is a sensor and software package designed to detect launch vehicle failures, alert the crew, initiate aborts, and trigger the Launch Abort System. The EDS is designed as a bolt-on kit to modify Atlas V and Delta IV families of vehicles with minimal impact to performance. Once developed, the EDS will help the Atlas V and Delta IV launch vehicles achieve key safety requirements for human rating the vehicles, including dual fault tolerance to loss of mission.

United Launch Alliance (ULA) and its partners are developing the EDS as part of NASA's Commercial Crew Development (CCDev) program. In spring 2010, Pratt & Whitney Rocketdyne received a contract to support ULA in designing and developing the EDS.[2] Special Aerospace Services and the National AeroSpace Training and Research (NASTAR) Center also support ULA by providing testing services, including crew response testing to improve crew interaction with the EDS system. Initial testing at the NASTAR Center was completed in August 2010.[3]

### Autonomous Flight Safety System – NASA Goddard Space Flight Center, NASA Wallops Flight Facility, United States Air Force, and Defense Advanced Research Projects Agency

AFSS

The Autonomous Flight Safety System (AFSS), managed from Wallops Flight Facility (WFF) in Virginia, is designed to reduce costs associated with range safety by incorporating flight termination decisions within the vehicle's onboard processors. The system augments or replaces functions of traditional range safety systems. It expands the range safety envelope, because it is not limited by local radio frequency interference. In addition, because the onboard AFSS is integrated with the vehicle's systems, it can cut down the time necessary for emergency flight termination. If successful, AFSS could be used by commercial launch vehicles.

On September 21, 2010, WFF successfully launched a Terrier-Orion sounding rocket to test AFSS technologies. AFSS software was tested during the flight, using a signal to simulate destruction of the vehicle based on deviations from a programmed flight path. However, no actual destruct ordinance was flown. This was the third AFSS test flight, and more are planned before the system can become flight certified.[4] The second was DemoFlight 2, launched aboard a SpaceX Falcon 1 from Kwajalein Atoll in 2007. Despite a second stage launch failure at 289 kilometers (180 miles) altitude, valuable AFSS data was gathered during flight.[5] The first test flight of an AFSS payload was at White Sands Missile Range in April 2006.[6]

### Commercial Orbital Transportation Services Ultra High Frequency Communication Unit – Space Exploration Technologies Corportation

The Commercial Orbital Transportation Services (COTS) Ultra High Frequency Communication Unit (CUCU) provides a data link between the International Space Station (ISS), SpaceX's Dragon capsule, and ground control. This system also enables astronauts on the ISS to monitor and control Dragon during uncrewed cargo missions.

CUCU

Developed by SpaceX under a NASA Space Act Agreement, the CUCU enables the ISS crew to send commands to and receive acknowledgments from the Dragon. The CUCU further exchanges navigation and status data between the Dragon and the ISS. It also provides a communications path between SpaceX Mission Control and the Dragon and can support audio for possible crewed Dragon missions. Weighing approximately 29 kilograms (64 pounds), a CUCU was launched aboard STS-129 in November 2009 and stowed in the ISS ExPRESS 7 rack.[7] The CUCU hardware successfully completed on-orbit checkout in March 2010.[8]

## Life Support

Crew capsules and in-space habitats currently in development require new life-support systems. Several companies are developing environmental controls and life support systems (ECLSS) or air revitalization systems for use in commercial space systems. Air revitalization system technologies support short-duration crew accommodations, like orbital transport vehicles. In contrast, ECLSS is designed to support space stations and other long-duration habitats. Some companies are developing customized life-support systems or are modifying previously developed systems for specific future vehicles and habitats. Other approaches include generalized, modular life-support systems that are applicable to a number of crew capsules. In 2010, two life-support technologies for commercial human spaceflight reached new milestones, described below.

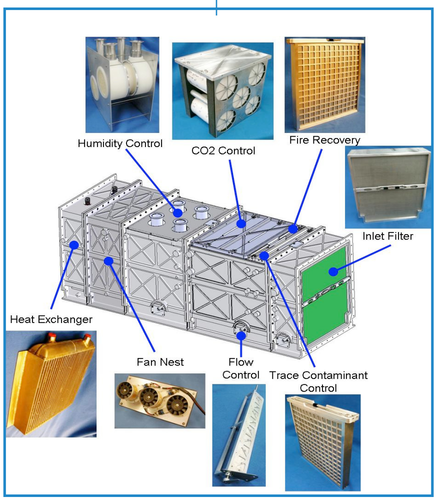
### Environmental Control and Life Support System – Bigelow and ORBITEC's Human Support Systems and Instrumentation Division

Bigelow Aerospace is developing an ECLSS for its next-generation expandable space habitats. The first system will support the needs of Bigelow Aerospace's Sundancer module, which provides roughly 180 cubic meters (6,200 cubic feet) of usable volume and can sustain a crew of three.[9] Specifically, in 2010, Bigelow Aerospace hired Orbital Technologies Corporation (ORBITEC) to begin ground tests of its ECLSS with human volunteers. Eight-hour-long tests were conducted at ORBITEC's facilities in Madison, Wisconsin. Bigelow engineers served as volunteers for the demonstration. Future tests will last longer and include additional personnel.[10]

Specific systems integrated for these initial tests included thermal and humidity control, ventilation, carbon dioxide removal, trace contaminant removal, atmospheric monitoring, and vehicle thermal control. Additional systems will be included as they become available.

The testing was conducted to validate the systems before their integration into larger, full-scale mock-ups of the Sundancer at Bigelow Aerospace's North Las Vegas facility.

### Commercial Crew Transport-Air Revitalization System – Paragon Space Development Corporation




Paragon's air revitalization system

Paragon Space Development Corporation is developing a modular air revitalization system for commercial crew transport vehicles.[11] The air revitalization system provides atmospheric control during relatively short flights to low Earth orbit. It is designed as a drop-in system for any commercial crew vehicle and to meet or exceed NASA's human flight safety standards. Paragon's system is self-contained, removes trace contaminants, scrubs carbon dioxide, cools the air and provides humidity control, and filters particulates. The air revitalization system design was developed with input from commercial crew vehicle developers. It has a footprint of 152x36x39 centimeters (60x14x12 inches).[12]

This project completed preliminary design review in 2010 and receives funding in part through NASA's CCDev program. Paragon has manufactured an engineering development unit, and ground tests were completed in the fall of 2010.[13]

## Propulsion

Propulsion systems for commercial spacecraft include liquid rocket engines, solid rocket motors, propellant for these systems, and associated subsystems. This section divides propulsion systems into engines and propellants.

### *Propulsion – Engines and Components*

Rocket and spacecraft developers invest in new engines to support suborbital and orbital space flight. Currently, cryogenic liquid engines, hydrocarbon liquid engines, solid rocket motors, and non-toxic liquid/solid hybrids are in development. Contractors and systems developers are maturing engine technologies for commercial spaceflight vehicles and government rockets.

### Bi-propellant, Mono-propellant, and Solid Rockets – Aerojet

Aerojet contracts with the Department of Defense on rocket development and is also providing multiple engines to Lockheed Martin for NASA's Orion Crew Capsule. In 2010, Aerojet met milestones on these contracts and has delivered, tested, or begun development on several new and modified engines.

On July 15, Aerojet delivered an AJ26 oxygen kerosene engine to NASA's Stennis Space Center for testing.[14] Orbital Sciences Corporation will use this engine for the Taurus II launch vehicle. The AJ26 engine is a commercial derivative of the Russian NK-33 engine designed and built in the late 1960s. The AJ26 is the world's first oxidizer-rich, staged-combustion, kerosene engine.

AJ26

LOX/Liquid Methane Engine

In spring of 2010, Aerojet completed testing of a liquid-oxygen, liquid-methane technology demonstration rocket. Aerojet developed the engine to test new technologies under the NASA Propulsion and Cryogenics Advanced Development Project. The engine provides 22,241 newtons (5,500 pounds) of thrust at about 350 seconds of specific impulse. Aerojet completed sea-level test firings in the summer of 2009 and conducted altitude testing at NASA's White Sands Test Facility in 2010. This engine may lead to systems that enable long-duration, in-space cryogenic propellant storage or propellant harvesting on Mars.[15]

Aerojet, with support from Florida Turbine Technologies, provided the Air Force Research Laboratory with a liquid-hydrogen turbopump technology demonstrator. The pump rotates at 90,000 revolutions per minute and is outfitted with sensors to monitor performance. Aerojet announced the development in 2010, and testing will continue into FY 2011.[16]


Liquid Hydrogen Turbopump Demonstrator

### Draco – SpaceX

Draco, a SpaceX designed and developed thruster, is used for orbital maneuvering and attitude control of the Dragon spacecraft. The Draco thrusters can generate up to 400 newtons (90 pounds) of force, and they can fire in bursts as short as a few milliseconds for precision maneuvering, or up to several minutes for orbital maneuvering. Depending on the mission, each Dragon spacecraft will use as many as 18 Draco thrusters that receive propellants from eight spherical titanium propellant tanks. Four tanks carry monomethyl hydrazine fuel, and four tanks carry nitrogen tetroxide oxidizer. These propellants have long on-orbit lifetimes, permitting future Dragon flights to remain in space for a year or more. A system of valves provides redundant cross-connection between the propellant tanks for maximum reliability. The Draco thrusters will be used by the Dragon spacecraft for orbital insertion, docking maneuvers, and deorbiting.[17]

Draco Thrusters

In December 2010, SpaceX successfully tested on-orbit maneuvering of a Dragon vehicle during the first test flight under NASA's COTS Space Act Agreement.

### High Performance Cryogenic Piston Pumps – XCOR Aerospace

Cryogenic Piston Turbopump

In June 2010, XCOR and ULA announced the first successful demonstration of XCOR's cryogenic piston pump. The pneumatically powered test device is designed to pump liquid hydrogen. Unlike traditional turbopumps, which rely on rotating machinery, XCOR's rocket engine pumps use one or more pistons to accelerate propellant into the combustion chamber. XCOR's piston pumps have demonstrated longer life and lower costs than turbo machinery and have been validated with liquid oxygen and nitrogen. In addition, catastrophic failure of a piston pump is far less destructive to adjacent hardware than failure of a turbopump.[18]

Under a fixed-price contract with ULA, XCOR developed a technology demonstrator, based on previous designs, to extend cryogenic pump applications to liquid hydrogen. Through a rapid development and test phase, XCOR demonstrated liquid-hydrogen pump technology and will continue to mature the technology with ULA. In addition to nine different rocket engines in its product line, XCOR's cryogenic pump technology may enable in-space propellant transfer and other cryogenic fluid management applications.[19]

### Liquid/Solid Hybrid Rocket Motor – Sierra Nevada Corporation

On September 21, 2010, Sierra Nevada Corporation conducted three test firings of its liquid/solid hybrid rocket motor design, completing two development milestones for NASA's CCDev prgram. The rocket provides the simplicity of a solid motor with restart and throttle ability. The hybrid rocket technology uses nitrous oxide as an oxidizer and synthetic rubber (hydroxyl-terminated polybutadiene) as a solid fuel. Both materials are non-toxic.[20]

Sierra is developing liquid/solid hybrid motors for its Dream Chaser space plane. Sierra has partnered with Scaled Composites to develop a similar hybrid motor for SpaceShipTwo, specifically RocketMotorTwo. Sierra and Scaled have conducted five hot-fire tests of RocketMotorTwo, most recently in August 2010. In addition, Sierra has developed several liquid/solid hybrid motors for the Air Force.[21]

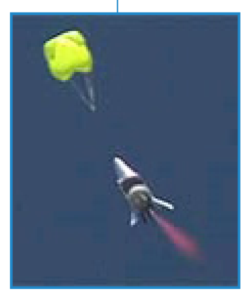
## Liquid Oxygen/Liquid Hydrogen Cryogenic Engines – Pratt & Whitney Rocketdyne

Pratt & Whitney Rocketdyne develops and manufactures cryogenic engines that can support commercial space flight. In 2010, three liquid-oxygen, liquid-hydrogen engines reached development milestones. However, this report profiles only the RS-68, because it is used on a commercially available vehicle, the Delta IV.

RS-68A

In February 2010, Pratt & Whitney Rocketdyne completed the first hot-fire test of the new RS-68A engine. This engine is an upgrade of the RS-68 engine. RS-68A will provide almost 178 kilonewtons (40,000 pounds) of thrust more than its predecessor and will increase fuel efficiency for the Delta IV. Additional hot-fire tests are planned, followed by design certification and flight readiness testing.[22]

## Vertical Take-off and Landing Engine Restarts – Masten Space Systems and Armadillo Aerospace



Xombie

Using different techniques, Masten Space Systems and Armadillo Aerospace have demonstrated in-air re-light capabilities. In late May 2010, Masten's Xombie was the first vertical take-off and landing vehicle to demonstrate in-flight re-light capability. Masten's approach involved boosting to a sufficient altitude, cutting the main engine and coasting for about two seconds, then re-lighting the engine during free fall. About ten days later, Armadillo aerospace demonstrated a different technique for in-flight restarts. Armadillo boosted its MOD (shorthand for "modular") vehicle to 2,000 feet, cut the engine and deployed a parachute, then restarted the engine and cut the parachute before landing. In both test flights, the vehicles quickly reestablished controlled flight and stabilized for safe landings. In-flight engine restart is a key capability for vertical take-off and landing reusable vehicles with powered descents, and these test flights can enable more challenging flight tests in the future.[23]

## X-51A WaveRider – Air Force Research Laboratory, Defense Advanced Research Projects Agency, NASA, Boeing Phantom Works, and Pratt & Whitney Rocketdyne

X-51A

On May 26, 2010, the X-51A WaveRider scramjet successfully completed its first flight, setting a supersonic combustion ramjet (scramjet) record for longest powered flight. An Air Force bomber carried the WaveRider to a cruising altitude and released it. A solid rocket motor accelerated the WaveRider until it reached about Mach 4.5, when the solid rocket motor separated from the scramjet. Then the supersonic combustion engine accelerated WaveRider to Mach 5 and an altitude of 70,000 feet.

Telemetry from the X-51A flight will help refine future flights; technology developed under the X-51 program could support first-stage scramjets or suborbital vehicles for commercial spaceflight.

Boeing Phantom Works is responsible for the overall design, assembly, and testing of the WaveRider. Pratt & Whitney Rocketdyne developed the fuel-cooled scramjet engine, which heats JP-7 jet fuel for increased combustion efficiency, while protecting the engine from high operating temperatures.[24]

#### *Propulsion – Propellants*

In addition to engine development, research continues in the development and testing of new propellants. Focus areas for propellant development include non-toxic storable propellants, improved solid rocket propellant, high-energy additives, new fuels for atmospheric breathing engines like ramjets, and liquid oxygen methane propellant. In 2010, there was one significant advancement in propellant technology.

### AerGen™ Solid Ramjet Fuel – Aerojet

In 2010, Aerojet announced successful ground tests of an advanced solid ramjet fuel. The fuel is from a family of fuels collectively called AerGen™. Solid ramjet fuel provides an alternative to traditional liquid ramjet fuels for tactical missiles and other applications that require storable fuel. The fuel was tested in a full-scale engine within a simulated high-altitude and high-speed environment. AerGen™ is designed for throttleable ramjets and burns efficiently, increasing energy and reducing smoke. AerGen™ may be applicable to other solid fuel applications, including solid rocket motors, hybrid motors, and commercial ramjets.[25]

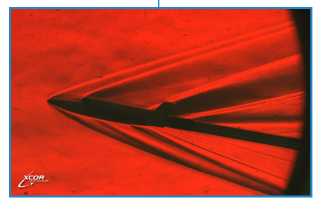
## Structures

Structures, materials, and vehicle designs can enable new capabilities for commercial space flight. Small changes, like new aluminum alloys for propellant tanks, can provide incremental improvements in overall vehicle performance. In 2010, spacecraft developers refined vehicle bodies, improving stability, safety, and performance.

### Lynx Aerodynamic Validation – XCOR

Lynx will use a lightweight but strong all-composite airframe. A thermal protection system will cover the nose cap and leading edges of the wings to protect these vulnerable areas from the heat of reentry.

On September 20, 2010, XCOR announced the successful completion of supersonic wind tunnel testing of a precision-scale model of the Lynx suborbital spacecraft. Tests at NASA's Marshall Space Flight Center confirmed that the Lynx can maintain stable flight throughout the projected flight profile. These tests also provided data to refine the design. Previous sub-sonic tests highlighted design flaws that required minor changes to spacecraft body for stability. These changes were evaluated in Marshall's wind tunnel, and the results indicate the stability issues were corrected. XCOR plans a final set of wind tunnel tests before vehicle assembly.[26]



Lynx Wind Tunnel Test

## Space Suits

A space suit is a full-pressure protective garment with an integrated environmental support system designed for extravehicular activity. It may also be worn as a safety measure against loss of cabin integrity. A typical space suit will include a hard shell or multi-layered fabric body garment, which may be divided into two pieces to accommodate the upper and lower portions of the body. The suit will also feature boots, gloves, and a helmet, each enabling a pressure-sealed interface. Finally, the suit will depend on a life support system, usually stored in a backpack, and a communications system. The life support system will provide pure oxygen for breathing, a system for scrubbing carbon dioxide waste gas, and a system for controlling humidity. The suit may also be designed with fittings for external life support and communications systems, configured to accept inputs from a portable unit or the spacecraft itself.

For purposes of this report, only space suits available for commercial use in the United States are described.

### Contingency Hypobaric Astronaut Protective Suit – David Clark Company, Inc.

The Contingency Hypobaric Astronaut Protective Suit (CHAPS) is designed for intravehicular activity (IVA) only. The suit, which weighs less than nine kilograms (20 pounds) and fits in a volume of about 0.2 cubic meters (one cubic foot), protects the wearer from loss of cabin pressure and hypothermia, should an emergency splashdown occur. Use of the CHAPS will be intuitive and produce minimal interface with the vehicle.[27]

CHAPS consists of a two-ply coverall, helmet, and gloves. The coverall will accept a variety of gloves and helmets, providing flexibility of mission requirements and other considerations. The coverall also features a pressure-sealing rear entry and soft, flexible joints.

CHAPS

In 2010, David Clark continued research and development work on CHAPS, though at a low level. Most of the work has focused on identifying and adapting suit interfaces to whatever vehicle system it is expected to serve.

### I-C2 Commercial Launch Suit – ILC Dover


ILC Dover Suit

Delaware-based ILC Dover has been in the business of developing helmets and pressure suits since the 1950s. In 1965, ILC Dover was selected as prime contractor for the Apollo space suits, and in 1977 it was awarded a contract to develop the space suits used for the Space Shuttle program. The company also produces protective suits for those working with hazardous materials.[28]

ILC Dover has been developing the I-C2 Commercial Launch Suit for potential commercial use, leveraging work from its I-Suit program, started in 1997 under a NASA contract. The I-Suit program determined the state-of-the-art in space suits and pursue improvements based on experiences gleaned from decades of experience.

The I-C2 suit consists of a pressure garment with waist entry and a moisture vapor permeable bladder. A liquid cooling garment is worn under the suit for temperature control. The pressure garment's outer cotton layer is fire resistant, and it features safety reflectors and hand holds for emergency rescue. The joints facilitate maximum flexibility. The gloves are attached using a typical ring connector around the wrist. The boots are standard issue military-style jump boots, similar to those worn by astronauts during the ascent and descent phases of Space Shuttle flights.[29]

A soft helmet is permanently attached to the pressure garment via a soft pressure-sealing closure, and it contains impact-protected communications equipment.


IS$^3$

### Industrial Suborbital Spacesuit (IS$^3$) – Orbital Outfitters

Orbital Outfitters, with offices in Washington, DC, and North Hollywood, California, was established to provide space suits for the emerging suborbital tourism market. The company has designed its first suit, called the full pressure Industrial Suborbital Spacesuit (IS$^3$). The primary purpose of IS$^3$ is to protect the wearer from loss of vehicle cabin pressure. Operational testing of the suit began in 2007.

The company has since done significant work in developing IVA suits for orbital and suborbital vehicles and has done component-level suit development work for NASA.[30]

# PRIZES AND COMPETITIONS

Prizes and competitions have been used in the aerospace industry since the beginning of powered flight and have played an essential role in innovation and public outreach. These prizes, once focused exclusively on airships and aviation, such as the famous Orteig Prize won by Charles Lindbergh, now include competitions related to spaceflight.

Inspired by the Orteig Prize's influence on aviation, the X PRIZE Foundation was established in 1995 to design and manage high technology competitions, including in the field of aerospace. The first was the Ansari X PRIZE. It was announced in 1996 as the X PRIZE and renamed in 2004 when Anousheh and Amir Ansari contributed several million dollars to the purse. Mojave Aerospace Ventures won the prize with its SpaceShipOne vehicle on October 4, 2004. In the six years since, other prizes related to commercial space transportation have been established, including NASA's Centennial Challenges.[1]

## NASA Centennial Challenges

Established in 2005, the NASA Centennial Challenges program aims to enable aerospace technology development in the private sector that the agency can capitalize on for future missions. NASA has conducted 20 Centennial Challenges and awarded a total of $4.5 million to 13 teams. The advantage of such an approach is that it promotes competition and cooperation on technically complex challenges. The Challenges program and prizes encourage independent teams to race to achieve bold goals in science, technology, engineering, and mathematics education without any upfront government funding. It fosters relationships between schools, laboratories, industry, and individual inventors. NASA provides the prize purses, but corporate sponsors are needed to fund the competitions themselves. Non-profit organizations manage the competitions.

In 2010, NASA announced a new space transportation-related challenge called the Nano-Satellite Launch Challenge, with a total purse of $2 million. The objective is to place a small satellite into orbit, twice in one week.[2] NASA continues to seek sponsors for the event.

## Google Lunar X Prize

X PRIZE Foundation Chairman and CEO Peter Diamandis approached Google about sponsoring a new competition focused on a Moon-related objective. Google agreed to sponsor, and a purse was established at $30 million. Teams from around the world that are 90-percent privately financed may compete. Twenty teams are now registered.

The objective of the competition includes the successful launch of a rover to the Moon. After landing, the rover must traverse the lunar surface for a distance of at least 500 meters (1,640 feet) and transmit high-definition images and video to a receiver on Earth. Google Lunar X PRIZE Summits are held each year, sponsored by the X PRIZE Foundation, to determine how the teams are progressing. The fourth annual summit was in October 2010.

The $20 million Grand Prize will be awarded to the first team that successfully meets the prize conditions by December 31, 2012. After that date, the value will drop to $15 million. The second team to successfully complete the requirements of the prize will win $5 million. Another $5 million will be awarded in bonus prizes, allocated for key technological developments and advancements in education. If no one wins the prize by December 31, 2014, it will expire.

Space Florida, a Google Lunar X PRIZE Preferred Spaceport Partner, will award $5 million independently of the Google Lunar X PRIZE to the winning team that uses its spaceport for the mission. SpaceX, which offers the Falcon 1 and Falcon 9 orbital launch vehicles and is the prize's Preferred Launch Provider Partner, will offer a ten-percent discount to any team using their products. Other preferred partners include the SETI Institute and Universal Space Network for communications services and Analytical Graphics, Inc. for software services.

As part of its Innovative Lunar Demonstrations Data program, NASA awarded contracts to six of the Google Lunar X Prize teams. Under the contracts, which have a total value of up to $30.1 million over five years, the teams will provide NASA with data on technical component demonstrations for lunar missions.[3]

# HUMAN SPACEFLIGHT TRAINING

The Commercial Space Launch Amendments Act of 2004 established the regulatory framework for commercial human space flight. The law established an "informed consent" protocol for carrying spaceflight passengers and created a new experimental launch permit for test and development of reusable suborbital launch vehicles. The Informed Consent rules became effective in February 2007 and the experimental permit rules became effective in April 2007.

The rules require launch vehicle operators to provide safety-related information to passengers and to identify what rules an operator must follow to conduct a licensed launch with human passengers. All spaceflight passengers must be fully advised, in writing, of the risks associated with human spaceflight, and they must agree to accept those risks. The protocols also include training and general security requirements for spaceflight participants.[1]

As part of the measures, launch providers must also establish requirements for crew notification, medical qualifications, and training, as well as requirements governing environmental control and life support systems (ECLSS). An operator must also verify the integrated performance of a vehicle's hardware and any software in an operational flight environment before carrying a spaceflight passenger.[2]

As private industry comes closer to testing vehicles that will be capable of taking tourists on suborbital flights, 13 organizations have begun to provide human spaceflight training.

## Astronauts for Hire

Florida-based Astronauts for Hire (A4H), founded in April 2010, is a non-profit organization that provides experienced personnel who can tend to microgravity experiments launched aboard commercial suborbital vehicles. Corporate sponsors and private donations provide the funding to operate the organization. A4H enables interested candidates to apply as commercial flight researchers through an online registration process. A4H matches candidates with customers seeking flight researchers with specific capabilities and experience.

| | |
|---|---|
| Location | Holiday, Florida |
| Company Description | Provides training for suborbital researchers and payload monitoring personnel. |
| Overview of Services | Provides a non-profit "match-making" service linking suborbital principle investigators with trained flight researchers. Flight researchers can tend to payloads, monitor payloads, or be available as subjects in aerospace medical research. |

Flight researchers provide a necessary service when an experiment's principle investigator (PI) is not medically qualified for space flight. The PI might be required to remain on the ground to monitor telemetry from the payload, or the PI might not be willing to take the risk of a space flight. In addition, the PI's employer might prefer to contract professional flight services.[3]

Applicants typically have several hours of microgravity experience attained aboard parabolic training aircraft, like Zero Gravity Corporation's (ZERO-G) specially modified Boeing 727-200. Other forms of experience include pilot certifications, neutral buoyancy extravehicular activity (EVA) training, and graduate degrees in sciences and engineering. A4H hopes to become a primary resource for prospective research groups searching for qualified flight researchers for suborbital human-tended payloads. A4H flight researchers will also be available for aerospace medical research. By the end of 2010, 17 commercial flight researchers were available through A4H.

All A4H flight researchers undergo a comprehensive training program, which includes a series of formal courses, learning assessments, and skills training provided by various agencies. Required training programs for A4H members include the National AeroSpace Training Research (NASTAR) Center's Suborbital Scientist Training Program (profiled later in this section), ZERO-G's parabolic flight training program, scuba diving certification, emergency egress training, and academic learning modules. Advanced training activities will include survival training, accelerated free fall, high-gravity flight, and private pilot license. A4H flight researchers gain microgravity experience on atmospheric parabolic flights as the organization builds its network of customers.

### Aurora Aerospace

Aurora Aerospace, based in Tampa, Florida, provides a two-day training program featuring a combination of L-39 Albatross jet flights, microgravity flights, high-altitude training, simulator training, physiologic training, and medical certification. Students applying to the program also receive medical screening and certification by a board-certified physician. Classroom study includes an overview of the space environment and the physics of a suborbital flight. Successful completion of the program earns the student Aurora Aerospace's suborbital pre-qualifying certificate; however, this is not an FAA certification.

| | |
|---|---|
| Location | Tampa Bay, Florida |
| Company Description | Aurora Aerospace is an organization based at the St. Petersburg-Clearwater Airport offering commercial spaceflight training and medical screening for spaceflight. |
| Overview of Services | High Performance Jet, Zero-g (gravity) Flights, High Altitude/ Hypoxia Training, Spatial Disorientation Training, Simulator Training, Unusual Attitude Training, High-g (gravity), and High Performance Glider Training. |

Aurora provides four training packages. Only the first package results in a suborbital pre-qualification certificate upon successful completion. The second package includes two flights, one on an L-39 Albatross jet and another in a Rockwell 700. The L-39 is used for high-gravity maneuvers, and the Rockwell 700 is used for simulating microgravity. The third package is a variety of experiences, including single flights on the L-39 jet or the Rockwell 700 or a single training session in the altitude chamber. The first three packages include movies of the flight experiences, but the fourth option does not. The fourth package is provided through Aurora Aerospace's association with the non-profit organization Americans in Orbit – 50 Years.

Aurora conducted several microgravity flights in 2010. One flight carried the youngest person to experience microgravity. Another flight accommodated a French news crew looking for an inexpensive parabolic flight.[4]

Barrios TITAN console

## Barrios Technology

Barrios Technology is a small business headquartered in Houston, Texas. Barrios has over 30 years of experience providing aerospace engineering, operations, and related technology services, including crew and flight controller training. The company's engineering and operations services support research, development, testing, and evaluation of a variety of space vehicle systems, including guidance, navigation and control; avionics; communications; space vehicle electrical systems; and ECLSS.[5]

Barrios leverages its knowledge of space systems, operations, and human factors to provide comprehensive training plans and services. These include needs analysis, curriculum development, and delivery of courses in a classroom setting or through distance learning technologies. Barrios instructors develop simulations and training scripts that model onboard systems and provide instruction for crew and flight controllers. Barrios instructors use simulator facilities located at NASA's Johnson Space Flight Center in Texas.

| | |
|---|---|
| Location | Houston, Texas |
| Company Description | Barrios Technology is an aerospace engineering and technology services firm. |
| Overview of Services | Provides space vehicle curriculum development, course scripting, and lecturing services in classroom or via distance learning technologies. Currently developing ISS cargo integration protocols for SpaceX and Orbital. |

During 2010, Barrios started working with SpaceX and Orbital Sciences Corporation (Orbital) to establish cargo integration protocols for the International Space Station (ISS). This ongoing effort aims to assist in smooth delivery of supplies and equipment to the ISS.

## Executive Aerospace Physiology Training

The Institute for Exercise and Environmental Medicine (IEEM) is located at the Presbyterian Hospital in Dallas, Texas. Its primary focus is researching "oxygen cascade," that is, how atmospheric oxygen is processed through the body's pulmonary, cardiovascular, and muscle systems to support physical activity. As an extension of this research, IEEM offers high-altitude, physiologic-based training for qualified applicants via the Executive Aerospace Physiology Training (EAPT) program.

| | |
|---|---|
| Location | Dallas, Texas |
| Company Description | The Institute for Exercise and Environmental Medicine (IEEM) consists of six physicians and eight technical support staff. Physicians of the IEEM, in cooperation with Johnson Space Center, are actively involved with studying the cardiological effects of spaceflight on NASA astronauts. As an integral part of the IEEM, Executive Aerospace Physiology offers services that include high altitude aerospace physiology, high altitude human research, as well as high altitude equipment research and testing. Executive Aerospace's multiplace chambers are certified for both hypobaric and hyperbaric operations. |
| Overview of Services | Aerospace physiology, hyperbaric oxygenation, flight physicals, decompression sickness, medical evaluation flights, and aerospace medical consultations. |

EAPT provides a half-day course on potential medical problems related to high-altitude flight. Topics include atmospheric physics, hypoxia, hyperventilation, the effects of pressure change, self-imposed stress, visual illusions, and aircraft pressurization. In addition to coursework, one hour is spent training in an altitude chamber. Students are required to pass a medical examination before entering the course, and pilots are required to be current on their FAA physical.

EAPT also provides a four-day course for advanced high-altitude training, generally intended for flight crews. Topics include high-altitude weather and aerodynamics, line-oriented flight training (a type of simulator training involving crews, rather than a single pilot), aircraft systems, and time in an altitude chamber.

The IEEM's current director is a cardiologist and an expert in space medicine. He also serves as team leader for the Cardiovascular Alterations Team of the National Space Biomedical Research Institute. A number of IEEM investigators have active experiments being performed on the ISS.[6]

## FAA Civil Aerospace Medical Institute

The FAA's Civil Aerospace Medical Institute (CAMI), based in Oklahoma City, Oklahoma, is the medical certification, research, education, and occupational health wing of the FAA's Office of Aerospace Medicine. CAMI traces its heritage back to 1946, when it was established by the Civil Aeronautics Administration. Since its inception, CAMI's focus has been on the human element in aviation. Recently CAMI was called upon to contribute its expertise to the emerging field of commercial human space flight.

| | |
|---|---|
| Location | Oklahoma City, Oklahoma |
| Company Description | The mission of the Federal Aviation Administration's Civil Aerospace Medical Institute (CAMI) is to create, apply, manage, and transfer aerospace medicine and human factors knowledge. CAMI's vision is to advance flight safety through world leadership in aerospace medicine. CAMI is part of the the Office of Aerospace Medicine and is located at the Mike Monroney Aeronautical Center in Oklahoma City, Oklahoma. |
| Overview of Services | CAMI provides services in aerospace medical/safety/human factors education, medical certification, human factors research, medical research, and occupational health. These aerospace services are provided by a workforce including biologists, computer specialists, engineers, nurses, physicians, physiologists, psychologists, and other professional and technical personnel. Also provided guidelines for commercial human spaceflight for FAA/AST. |

In 2003, the institute was integral to developing medical screening guidelines for commercial human space flight. Subsequently, these were adopted in the FAA's 2005 *Draft Guidelines for Commercial Suborbital Reusable Launch Vehicle Operations with Space Flight Participants*.[7]

CAMI's expertise in training pilots and crew is leveraged to inform training for space vehicle crews. For example, CAMI provides training on aviation physiology, with a curriculum that focuses on high-altitude physiology, respiration and circulation, hypoxia and hyperventilation, decompression sickness, trapped gasses, and spatial disorientation. These are all relevant to human space flight. The institute's aviation survival training includes water survival, cold weather survival, desert survival, familiarization and use of survival kits, field first aid, and signaling.[8] This training could assist surviving crew and passengers after a faulty landing or a crash on land or at sea. Individuals also have the opportunity to register for CAMI training courses.

### National Aerospace Training and Research

The NASTAR Center, a subsidiary of Environmental Tectonics Corporation, is based in Southampton, Pennsylvania and began operations in 2007. The center provides a variety of aerospace training, research, education, and flight simulation experiences for commercial customers. On April 7, 2010, the FAA issued its first Spaceflight Training System safety approval to the NASTAR Center.[9] This certification states that the NASTAR Center is able to meet the FAA crew qualification and training requirements of 14 CFR Section 460.5. The approval process involved a thorough review of the design and operation of the company's Space Training Simulator-400 (STS-400) and an on-site evaluation by FAA officials.[10] STS-400 can replicate a variety of crewed suborbital and orbital flight profiles, and it serves as an integral component of spaceflight training for launch providers, vehicle operators, and other clients.

The NASTAR Center provides training, research, and education services for the aerospace community. The center's space training programs provide medical screening and spaceflight qualification for flight crew and spaceflight participants. The center provides four core training programs:

- Suborbital and orbital training for vehicle operators, crew, and passengers,
- Payload specialist training for space researchers and students,
- Tactical and aeromedical training for military pilots, and
- Upset recovery, spatial disorientation, and altitude training for general aviation pilots.

The suborbital and orbital training programs include curriculum in space physics, motion physiology, and aerospace medicine. They also provide comprehensive instruction on counter measure techniques to mitigate effects during spaceflight and simulated space flights on the STS-400 simulator. The payload specialist, or "Suborbital Scientist," training program is designed around the needs of researchers interested in suborbital space science applications and suborbital payloads they can personally escort in space or that are launched using crewed vehicles. The program includes altitude physiology training, space vehicle design and experiment considerations, distraction management exercises, and spaceflight training featuring simulated flight exposure in the STS-400. The NASTAR Center also provides an Ultimate Training and Weightless Program that features the same training described earlier, but also includes parabolic flights simulating microgravity. These flights are provided through Space Adventures' ZERO-G program.

The center also provides research and development testing including:

- Flight profile modeling and simulation,
- Nominal and off-nominal flight scenarios,
- Cockpit ergonomics and seat design,
- Emergency Detection System (EDS),
- ECLSS testing,
- Launch abort system testing,
- Human factors performance and feedback, and
- Payload and component testing.

STS-400

NASTAR introduced the 2010 Suborbital Scientist Class during the year. The class is composed of over 35 researchers educated on suborbital experiment design. Each student received altitude physiology instruction, spaceflight training, and distraction factor management. The center also participated in a research project with Drexel University's Human Cognition Enhancement Program to model and counter the negative effects of motion on the vestibular system in an effort to understand space sickness.

| | |
|---|---|
| Location | Southampton, Pennsylvania |
| Company Description | Provides three spaceflight training packages for prospective passengers and crew, including a two-day training program, a suborbital scientists training program, and a training package that includes microgravity simulation flights. |
| Overview of Services | 1. Flight Training: Rapid & Sustained Gravity Acceleration (Multi-axis), Medical Screening, Sub-Orbital Space Flight Training, Spatial Disorientation Training, Aircraft Upset Recovery (Loss of Control) Training, Tactical Flight Simulation & Training, Motion Desensitization, High Altitude Exposure and Rapid Decompression Training, Ejection Seat / Emergency Egress Training, Night Vision and Night Vision Goggle Training, Land/Water Survival Training, and the Space Training System Model 400 (STS-400).<br>2. Human Factors & Component Research: Research can be supported on all equipment including Medical Monitoring, Flight Profile Development & Test, Combined Environments Testing (Sustained G with Vibration) for HF and Component, and Hyperbaric Research Lab.<br>3. Educational and Entertainment programs are available for all ages. |

Also in 2010, NASTAR conducted research on the Atlas V EDS, under contract for Special Aerospace Solutions, to test crew response and EDS by modeling an Atlas V profile using the center's STS-400 Simulator.

## Orbital Commerce Project

Orbital Commerce Project, Inc. (OCP) is based in Florida and was founded in 2004. OCP provides emerging space transportation companies with support services, including training, ground support, and advertising support. OCP established a division called Black Sky Training to support companies providing suborbital transportation services. This division focuses on a two-part program that consists of introductory training followed by vehicular training.

| | |
|---|---|
| Location | Oviedo, Florida |
| Company Description | Currently develops a curriculum that includes suborbital spaceflight ground schooling, simulator training, and high-performance aircraft training. |
| Overview of Services | Physiological Training, Altitude Chamber (hypobaric), Unusual, Attitude Training, High-g (gravity), High Altitude Flight, Pressure, Suit Training, High Performance Glider, and High Performance Jet. |

OCP works with XCOR, Masten, and others to develop appropriate training tools. In 2010, OCP began to develop training that will use a modified Velocity Aircraft airframe. It is a transitional course for pilots going from traditional propulsion systems to rocket power. Pilots would then move into a RLV that can reach altitudes of 30,480 meters (100,000 feet) for final training. In addition, OCP develops curriculum in partnership with the Florida Institute of Technology (FIT). Anyone wishing to undergo OCP's training will likely be required to enroll with FIT; this decision is pending. The length of training will depend on the curriculum designed by OCP and FIT.[11]

OCP Cockpit Simulator

## Space Adventures

Space Adventures, based in Vienna, Virginia, and founded in 1998, arranges space flights and related services for private citizens. As of 2010, Space Adventures is the only company to arrange space flights for self-funded individuals. With seven customers, the company has a cumulative total of three months in space and 36 million miles traveled.[12]

| | |
|---|---|
| Location | Vienna Virginia |
| Company Description | Provides training services as part of suborbital or orbital flights or independently for those not planning actual space flights. |
| Overview of Services | The company offers cosmonaut overview training, Soyuz simulator training, centrifuge training, microgravity training, and EVA training. |

In 2008, Space Adventures announced the opportunity for a private Soyuz mission. This private spaceflight opportunity will be a fully dedicated mission of the Soyuz-TMA spacecraft. Two seats will be available for private space explorers, and the flight will include a comprehensive package of mission services, including science, education, and media program options. The first private mission to the ISS is offered not only to individual explorers but also to businesses, organizations, and institutions. Space Adventures' orbital spaceflight clients also have the availability to train, be certified, and conduct an EVA during their mission at the ISS. The 90-minute EVA would extend the client's stay at the station for approximately five days.[13]

Space Adventures also provides microgravity flights to the public through its subsidiary, ZERO-G, which operates a modified Boeing 727 for this purpose. ZERO-G was purchased by Space Adventures on January 1, 2008. Over 6,000 individuals have flown, including several hundred teachers, through Northrop Grumman Foundation's Weightless Flights of Discovery program.

In April 2010, Space Adventures announced a partnership with Armadillo Aerospace. This partnership plans to provide suborbital space flights with a ticket price of $102,000.[14] Space Adventures already has over 200 reservations for this flight profile. Space Adventures will also broker $200 million circumlunar flights, using a Soyuz spacecraft supplemented with a separately launched propulsion module. Space Adventures has also begun offering reservations aboard Boeing's CST-100 spacecraft, with flights scheduled for 2015.[15]

Space Adventures offers human spaceflight training services, either as part of the ticket price for flights aboard Soyuz or Armadillo's suborbital vehicle or as separate experiences. The company provides five training packages, including cosmonaut overview training, Soyuz simulator training, centrifuge training, neutral buoyancy EVA training, and EVA training. Space Adventures also offers a tour package to Baikonur Cosmodrome in Kazakhstan, the launching location for Soyuz flights.

## Space Medicine Associates

Space Medicine Associates (SMA) was formed in 2007 as a space medicine consultancy for space transportation providers and other clients. SMA has ready access to twelve member physicians and pharmacologists with aerospace medical and bioastronautics expertise, experience with operations training and support, risk management and mitigation techniques, and medical project management.[16]

| | |
|---|---|
| Location | Belcamp, Maryland |
| Company Description | An organization of medical professionals offering space medicine and bioastronautics consultation, training and oversight services. |
| Overview of Services | Comprehensive medical and bioastronautics expertise, operations training and support, risk management and mitigation techniques, medical project management, and assistance for all aspects of commercial and industrial space activities, from space tourism to space-based solar power. Space Medicine Associates plans to use client-based facilities. In 2009, Space Medicine Associates worked to establish relationships with organizations within the commercial human spaceflight industry. |

The types of work that benefit from SMA participation include human factors evaluations, development of medical screening surveys, in-flight health monitoring, radiation monitoring, and other space medicine issues.

## SpaceTEC

Florida-based SpaceTEC® , under an agreement with the National Science Foundation as a National Resource Center for Aerospace, provides aerospace technical education and training through 11 partner colleges. SpaceTEC® offers certifications in four areas: The Certified Aerospace Technician Core, Vehicle Processing, Aerospace Manufacturing, and Composites.

| | |
|---|---|
| Location | Kennedy Space Center, Florida |
| Company Description | Provides aerospace technical education and certifications. |
| Overview of Services | Provides certifications in Certified Aerospace Technician Core, Vehicle Processing, Aerospace Manufacturing, and Composites. |

The Certified Aerospace Technician Core is recommended by the American Council on Education for 24 college credits toward a technical degree. This certification covers general knowledge in introductory aerospace, applied mechanics, basic electricity, tests and measurements, materials and processes, and aerospace safety.[17]

## Starfighters Aerospace

Starfighters F-104

NASA's Kennedy Space Center, Florida is the operational home to nine Lockheed F-104 Starfighters, the largest private fleet of supersonic aircraft in the world. Starfighters Aerospace is the only commercial flight services corporation permitted to operate from the Space Shuttle Landing Facility under a cooperative Space Act Agreement with NASA.[18]

Starfighters Aerospace goal is to provide clients with high-performance flight test and support services, using the company's considerable tactical aircraft operations expertise. All nine aircraft are certified flight test platforms with the NASA Airborne Science Program Directorate located at the Wallops Flight Research Facility in Virginia.

| | |
|---|---|
| Location | Kennedy Space Center, Florida |
| Company Description | Provides suborbital training services using CF-104D aircraft, brokered through Incredible Adventures, a firm offering a variety of unique vacation experiences. |
| Overview of Services | Commercial services: High Performance Jet (Supersonic Flight), High Altitude Flight, High-G Flight (Gravity), Unusual Attitude / Upset Recovery Training, Micro-Satellite Air Launch, Aerospace Medical Evaluation, Flight Physiology Training, Altitude Chamber (Hypobaric), Aircrew Life Support & Egress/ Ejection Systems Training, Parachute Training, Pressure Suit Training.<br>Department of Defense services: Offensive & Defensive Counter Air, Advanced Electronic Jamming, WIC Support, NSAWC / Top Gun / SFTI, Large Force Exercise Participation (Flags), High Altitude Interception, Carrier Battle Group Threat Simulation / Ship Self Defense Targeting. |

The company provides the high-performance aircraft flight training for potential crews of RLVs, and suborbital participant flight training is for prospective passengers of suborbital flight.

In February 2010, Starfighters conducted the first space training flights for civilian clients, providing two Florida residents a sense of what suborbital passengers experience, including high-gravitational forces and microgravity.[19]

## United Space Alliance

United Space Alliance (USA) is a joint venture between Boeing and Lockheed Martin that was established in 1995 to provide streamlined day-to-day management of the Space Shuttle fleet. USA is also responsible for handling ISS operations, training, and planning. Using significant heritage experience that stretches well before the company's founding, USA has developed a comprehensive training capability to inform training available to commercial and international customers. For example, USA currently offers 837 certification courses focused on Space Shuttle systems, skills, safety, and quality control to its employees and contractors.[20]

| | |
|---|---|
| Location | Houston, Texas |
| Company Description | Trains commercial and international customers in the following areas that support human spaceflight operations: space systems ground operations and processing, spaceflight mission operations, space systems flight software development, space systems integrated logistics, and space systems integration and program management. |
| Overview of Services | Generic Skills/Proficiency, Documentation (Mission Rules, etc.), Simulator Operations (Task and Vehicle), Ground Operations, Mission Operations, Microgravity/EVA, Pressure Suit, Land and Water Survival, Parachute Training, and Flight Crew Equipment Training. |

In 2007, USA established Space Flight Operations, LLC (SFO). The types of training and guidance that SFO will offer include space systems ground operations and processing, spaceflight mission operations, space systems flight software development, space systems integrated logistics, and space systems integration and program management.[21]

## Wyle

California-based Wyle was founded in 1949 and provides aerospace and defense services to government and commercial clients worldwide. Wyle's Systems and Crew Training group focuses specifically on healthcare training for crews serving aboard the Space Shuttle and ISS, as well as flight surgeons and biomedical engineers. Training typically includes general hardware familiarization and maintenance of in-space health monitoring and medical equipment. The company also provides in-space emergency medical training and aerospace medical training to medical students and residents. Wyle's largest customers are the Department of Defense and NASA.

In August 2010, Wyle was selected as part of a Stanford University-led team to support the FAA's new Center of Excellence for Commercial Space Transportation. Wyle has supported more than two-thirds of people who have traveled into space since the 1960s. To support the Center of Excellence, Wyle will provide its expertise in space medicine and human spaceflight training for a variety of research projects.[22] The objective of the center is to help inform the FAA on matters that contribute to its role in regulating the commercial space transportation industry.

| | |
|---|---|
| Location | San Antonio, Texas |
| Company Description | Provides space medicine and on-orbit medical training for Space Shuttle and ISS crews. Wyle is part of a team that supports the FAA's Center of Excellence for Commercial Space Transportation on matters related to human spaceflight training and operations. |
| Overview of Services | Human Centrifuge Training and Medical Screening, Altitude Chamber Training and Medical Screening, Oxygen Systems Safety Services, and Decompression Sickness Assessments. |

# REGULATORY AND LEGISLATIVE DEVELOPMENTS

As the year 2010 began, two new programs in the FAA Office of Commercial Space Transportation (FAA/AST) were in their infancy:

- Center of Excellence for Commercial Space Transportation
- Commercial Space Transportation Infrastructure Matching Grant Program

These programs have now grown to allow new paths to encourage and facilitate the commercial space transportation industry.

This chapter describes where the programs are now.

## Center of Excellence for Commercial Space Transportation

The FAA's Air Transportation Centers of Excellence Program, which has a long and successful record, soared to new heights with the establishment of the Center of Excellence for Commercial Space Transportation (COE CST) in August 2010. On August 18, U.S. Department of Transportation Secretary Ray LaHood announced the new Center of Excellence and the outstanding university team selected by FAA Administrator, Randy Babbitt.

Led by the New Mexico State University in Las Cruces, the COE CST team includes Stanford University in California, the University of Colorado at Boulder, the University of Texas Medical Branch at Galveston, the New Mexico Institute of Mining and Technology in Socorro, the Florida Institute of Technology in Melbourne, and the Florida Center for Advanced Aero-Propulsion in Tallahassee, a research consortium consisting of the University of Florida in Gainesville, Florida State University in Tallahassee, and the University of Central Florida in Orlando.

The COE CST is a partnership of academia, industry, and government, developed for the purpose of creating a world-class consortium that will address current and future challenges for commercial space transportation. The new Center will focus on strategic research, education, and training to support commercial space initiatives over the next decade. The research and development efforts for the new Center will include four major subject areas: Space Launch Operations and Traffic Management; Launch Vehicle Systems, Payloads, Technologies, and Operations; Commercial Human Space Flight; and Space Commerce (including space law, space insurance, space policy, and space regulation). The FAA will enter into 50-50 cost-sharing cooperative agreements to establish the COE partnerships, with plans to invest $2,000,000 in the first two years and a minimum of $1,000,000 per year thereafter for the initial five years of COE operations.

## Origins of the COE CST

The FAA has long and successful partnerships with the nation's academic research community, working with U.S. colleges and universities to foster research by both faculty and students. This research has contributed significantly to the advancement of aviation science and technology and has provided the agency and the aviation industry a high return on its investment over the past decade.

To enhance its research efforts, FAA proposed establishing a Center of Excellence for Commercial Space Transportation to advance aerospace technology to meet the current and future needs of the U.S. commercial space transportation industry. On August 18, 2009, FAA Administrator Randy Babbitt signed a memorandum calling for establishing the new Center. From March 16 through May 4, 2010, the FAA solicited proposals from accredited institutions throughout the nation. AST received proposals from eight academic teams consisting of 37 universities and two research organizations. Each team's proposal was evaluated by a panel of subject matter experts (the technical evaluation) and reviewed by management and budget officials (the management/fiscal review). On August 18, FAA Administrator Babbitt selected the COE CST team.

Research from the COE CST will support the mission of FAA/AST to ensure protection of the public, property, and the national security and foreign policy interests of the United States during commercial launch or reentry activities, and to encourage, facilitate, and promote U.S. commercial space transportation.

## The FAA Air Transportation Centers of Excellence Program

Under Public Law 101-508 (49 USC Section 44513) Section 9209 Aviation Research and Centers of Excellence, the FAA Administrator may "make grants to one or more colleges or universities to establish and operate several regional centers of air transportation excellence…." Since 1990, this enabling legislation has allowed the FAA to enhance internal research efforts by accessing the various talents of nationally recognized university scholars and industry research scientists. By establishing major research centers throughout the country, FAA proactively creates a pool of technical professionals in the areas of aviation science and technology and, since August 2010, commercial space transportation.

The FAA COEs are required by Congress to match grant funds. This requirement helps to solidify significant partnerships between the COE members and the FAA. Through this partnership, the government, academic institutions, and industry leverage research resources and maximize technological competence. The FAA also may award contracts to successful applicants in a COE competition. This authority gives the COE the latitude to take basic research successes and continue to develop multiple forms of analysis, applications, and prototyping activities, thus providing products for the benefit of the agency as needed.

When an academic team is selected to be a COE, each university that makes up the team enters into a long-term cooperative agreement to conduct critical research in specific areas of interest to the FAA's mission and long-term vision. COE institutions are also required to conduct annual research reviews, actively participate in Joint COE Conferences, and host seminars and reviews to disseminate research results.

Under P.L. 101-508, institutions being considered for selection as a COE must demonstrate their ability to meet the following criteria:

- The extent to which the needs of the State in which the applicant is located are representative of the needs of the region for improved air transportation services and facilities.
- The demonstrated research and extension resources available to the applicant to carry out this section.
- The ability of the applicant to provide leadership in making national and regional contributions to the solution of both long-range and immediate air transportation problems.
- The extent to which the applicant has an established air transportation program.
- The demonstrated ability of the applicant to disseminate results of air transportation research and educational programs through a statewide or region-wide continuing education program.
- The projects the applicant proposes to carry out under the grant.

Since 1990, more than eight COEs have been formed with more than 60 university partners and over 200 industry and government affiliates participating in research projects. To learn more about the FAA Air Transportation Centers of Excellence Program, go to http://www.faa.gov/go/coe.

## Commercial Space Transportation Infrastructure Matching Grant Program

On December 31, 2009, Congress passed appropriations legislation (P.L. 111-117) that launched the Commercial Space Transportation Infrastructure Matching Grant Program with $500,000 appropriated for the first year. Previous authorizing legislation permits the grant program to expand up to $10 million, provided funds are made available.

In Fiscal Year 2010, FAA/AST made its first awards of discretionary matching grants to four separate licensed launch sites, located in Alaska, California, Florida, and New Mexico.

According to FAA Administrator Randy Babbitt, "The Obama administration is committed to making sure the United States remains the world leader in space development and exploration. This new grant program underscores that commitment and will help ensure that the commercial space industry can meet our current and future space transportation needs."

The grants include $43,000 for the New Mexico Spaceport Authority to provide an Automated Weather Observing System; $227,195 to the Alaska Aerospace Corporation for a Rocket Motor Storage Facility; $125,000 to the East Kern Airport District in Mojave, California, for an emergency response vehicle; and, $104,805 to the Jacksonville Airport Authority in Florida to develop a Spaceport Master Plan for Cecil Field. Under the program's authorizing legislation, the FAA can provide matching funds (up to 50%) for specific projects carried out by public entities involved in commercial space activities.

Dr. George Nield, the Associate Administrator for Commercial Space Transportation, said of the grants, "2010 marks the first year AST has had funds appropriated for this worthwhile program. We congratulate the grant recipients, and look forward both to working with them, and to continuing the program as long as funds continue to be available for it."

The Commercial Space Transportation Infrastructure Matching Grants are analogous to grants made by the federal government for airport improvements under the FAA's Airport Improvement Program (AIP). The purpose is similar: to expand and improve the infrastructure supporting an important transportation segment. However, AIP projects are funded by the airport trust fund, while the Commercial Space Transportation Infrastructure Matching Grants are dependent on Congressional appropriations.

For the latest news about Commercial Space Transportation Infrastructure Matching Grant Program, see AST's website at http://www.faa.gov/about/office_org/headquarters_offices/ast/grants_program/.

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# LIST OF ACRONYMS

A4H – Astronauts for Hire

AFB – Air Force Base

AFRL – Air Force Research Laboratory

AFSS – Autonomous Flight Safety System

AIP – Airport Improvement Program

APAS – Androgynous Peripheral Attach System

AsiaSat – Asia Satellite Telecommunications Company Limited

AST – Office of Commercial Space Transportation (within FAA)

ATK – Alliant Techsystems

ATV – Automated Transfer Vehicle

AWOS – Automated Weather Observing System

BLS – Boeing Launch Services

CAMI – Civil Aerospace Medical Institute (within FAA)

CBC – Common Booster Core

CBM – Common Berthing Mechanism

CCAFS – Cape Canaveral Air Force Station

CCB – Common Core Booster

CCDev – Commercial Crew Development

CERV – Crew Emergency Return Vehicle

CHAPS – Contingency Hypobaric Astronaut Protective Suit

CLV – Commercial Launch Facility

COE CST – Center of Excellence for Commercial Space Transportation

COTS – Commercial Orbital Transportation Services

CPM – Common Propulsion Module

CRS – Commercial Resupply Services

CRuSR – Commercial Reusable Suborbital Research Program

CST-100 - Crew Space Transportation-100

CUCU – COTS Ultra High Frequency Communication Unit

CST -100 - Crew Space Transportation-100

DoD – U.S. Department of Defense

EAPT – Executive Aerospace Physiology Training

ECLSS – Environmental Control and Life Support System

EDS – Emergency Detection System

EELV – Evolved Expendable Launch Vehicle

EIS – Environmental Impact Study

ELV – expendable launch vehicle

FAA – Federal Aviation Administration

FIT – Florida Institute of Technology

GNC – guidance, navigation, and control

GPS – Global Positioning System
GTO – geosynchronous transfer orbit
HX – hydrocarbon-X
IEEM – Institute for Exercise and Environmental Medicine
IOS – Interorbital Systems
IS – Industrial Suborbital Space Suit
ISS – International Space Station
IVA – Intravehicular Activity
JAA – Jacksonville Aviation Authority
KSC – Kennedy Space Center
LC – Launch Complex
LEO – low Earth orbit
LMCLS – Lockheed Martin Commercial Launch Services
LOX – liquid oxygen
MARS – Mid-Atlantic Regional Spaceport
MDA – MacDonald Dettwiler Associates
MNMS – Multipurpose Nanomissile System
MOD – modular
NASA – National Aeronautics and Space Administration
NASTAR – National AeroSpace Training and Research
NMSA – New Mexico Spaceport Authority
NSPO – National Space Organization
NSROC – NASA Sounding Rockets Operations Contract
OCP – Orbital Commerce Project
Orbital – Orbital Sciences Corporation
ORBITEC - Orbital Technologies Corporation
OSIDA – Oklahoma Space Industry Development Authority
PCM – Pressurized Cargo Module
PI - principle investigator
RLV – reusable launch vehicle
SETI – Search for Extraterrestrial Intelligence
SFO – Space Flight Operations, LLC.
SLC – Space Launch Complex
SMA – Space Medicine Associates
SMDC – Space Missile and Defense Command
SRPO – Sounding Rockets Program Office
SS1 – SpaceShipOne
SS2 – SpaceShipTwo
SSI – Spaceport Systems International
SS/L – Space Systems/Loral
SOST – Suborbital Space Transport

SpaceCom – Space Communications Limited
SpaceX – Space Exploration Technologies Corporation
SSTO – single stage to orbit
SXC – Space Experience Curacao
ULA – United Launch Alliance
USA – United Space Alliance
USAF – United States Air Force
USASMDC - U.S. Army Space and Missile Defense Command
VAFB – Vandenberg Air Force Base
VCSFA – Virginia Commercial Space Flight Authority
VTVL – Vertical Takeoff, Vertical Landing
WFF – Wallops Flight Facility
WFNA – white fuming nitric acid
XA – extreme altitude
ZERO-G – Zero Gravity Corporation