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QUARTERLY LAUNCH REPORT

Special Report:

U.S. & International Small Launch Vehicles

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Special Report

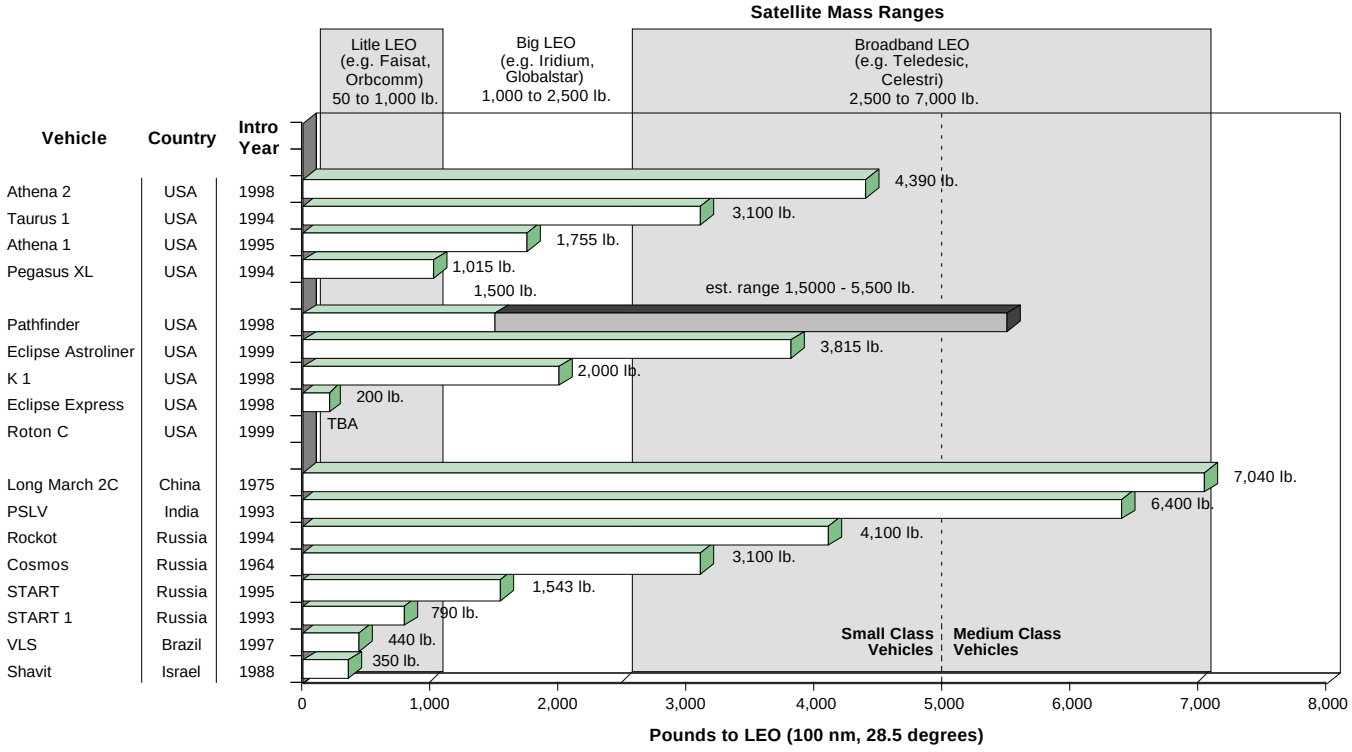
U.S. & INTERNATIONAL SMALL LAUNCH VEHICLES

Since the 1980s, there have been expectations that a substantial commercial market for launch services using small launch vehicles[1] would develop. In fact, commercial launches of small launch vehicles have, in theory, been available since the mid-1980s. However, the first commercial launch of a small vehicle did not occur until 1993. Since then, the market has been small, about one or two commercial launches annually, and until recently, only U.S. firms have served the market (the first non-U.S. commercial launch of a small vehicle occurred in December 1997).

There are now revitalized expectations that the market will become much larger in the next few years. These expectations are driven by the emergence of new commercial applications for small satellites in low Earth orbit – ideal payloads for small vehicles – and are fueling the development of new commercial vehicles by launch service providers around the world.

Constellations of small, commercial satellites will be used in low Earth orbit (LEO) to provide global wireless data and telephone services as well as international data networks; these constellations are sometimes called "big LEO" systems and use dozens and sometimes hundreds of satellites. The first of these systems to be deployed is the mobile satellite communication system Iridium, owned by Motorola and its international partners, which is currently in its

Figure 1. Worldwide Small Launch Vehicle Capabilities



[1] By FAA's definition, small launch vehicles are defined as being able to deliver no more than 5,000 lb. to low Earth orbit (LEO). For this report, a LEO orbit is defined as an orbit at 28.5 degrees and 100 nm altitude.

launch phase. The initial deployment of these massive constellations will generally not use small vehicles; they will be deployed in groups on larger launch vehicles, to minimize deployment costs. For example, in 1997, 46 Iridium satellites were launched on seven medium- and two heavy-class launch vehicles[2]; similar vehicles will launch the remaining 26 satellites in 1998. Group launches will not be feasible, however, for maintenance of these large constellations. Maintenance flights will be needed on a quick-turnaround basis to replace single satellite failures and for planned system replenishment in smaller numbers. It is expected that these operations and maintenance flights will primarily use small launch vehicles.

Small satellites will also provide many niche services such as store and forward e-mail, fleet tracking, and utility monitoring; these satellites and constellations are sometimes called "little LEOs" and may use a single satellite or several dozen. It is likely that these systems will use small launch vehicles. In fact, Orbital Sciences began full-scale deployment of the Orbcomm satellite system with the launch of eight Orbcomm satellites on a Pegasus this past December. Orbcomm is a little LEO system which will provide two-way data communications worldwide for e-mail, non-voice messaging, and fleet tracking.

The precise timing and size of the market for small launch vehicle services is uncertain, because of the recent emergence of commercial LEO satellite applications. However, many firms are offering commercial small launch vehicle services in anticipation of the success of these LEO applications. New firms in the United States and in other countries continue to enter the market. In addition to the conventional U.S. and foreign small launch vehicles, there has also been renewed interest in and pursuit of reusable launch vehicle (RLV) concepts. Several of these concepts are also targeting small satellites.

This report profiles each of the current U.S. and international small launch systems and the markets their operators are targeting. It includes an overview of the various reusable launch vehicle concepts in development and how their proponents hope they will become a competitive alternative to traditional expendable launch vehicles. Figure 1, on page 1 above, shows current and planned launch vehicle systems and their capacities.

U.S. Expendable Small Launch Vehicles

There are currently two U.S. small launch vehicle families in commercial operation: Lockheed Martin's Athena and Orbital Sciences Corporation's Pegasus and Taurus vehicles.

Athena

Lockheed Martin's Athena 1 launch vehicle, formerly the Lockheed Martin Launch Vehicle 1 (LMLV-1), is a two-stage solid propellant vehicle based on the Thiokol Castor 120 solid rocket motor. Since its initial demonstration flight which ended in failure, it has been redesigned and its management and manufacturing approach restructured. It is capable of putting 1,755 lb. into a LEO orbit. The Athena 2 (formerly the LMLV-2) is essentially an Athena 1 with an additional Castor 120 solid rocket motor. Its LEO capacity is 4,390 lb.

The Athena 1's first successful flight was the commercial launch of NASA's Lewis remote sensing spacecraft on August 23, 1997 (Lewis

[2] Medium class vehicles have maximum lift capacities between 5,001 lb. and 12,000 lb. to LEO, intermediate vehicles between 12,001 and 25,000 lb., and heavy vehicles greater than 25,000 lb. to LEO.

failed shortly after launch and was eventually lost). Lockheed Martin's earlier demonstration flight of the LMLV-1 on August 15, 1995, failed to deploy the GEMstar 1 payload for Volunteers in Technical Assistance (VITA).

The first launch of the larger Athena 2 deployed NASA's Lunar Prospector on January 6, 1998. The price for this commercial launch was approximately $28 million (the launch price for an Athena 1 is about $16 million).

There are five launches planned for Athena through 1999. Three of these are commercial launches of small remote sensing payloads: NASA's Clark satellite and Space Imaging's IKONOS 1 and 2. The remaining two launches are the commercial launch of the Taiwanese ROCSat and the non-commercial U.S. Air Force SBIRS LADS satellite.

Industry analysts believe Lockheed Martin could launch 12 or more Athena vehicles per year if demand warranted.[3]

Pegasus

Orbital Science Corporation's Pegasus XL is a three-stage, solid propellant, winged rocket that is air launched by an L-1011 carrier aircraft. It can place a 1,015 lb. payload into a low Earth orbit. It is currently the most active U.S. small launch vehicle with five launches in 1997, placing 13 payloads in orbit.

In the past, Pegasus has been primarily used to launch small engineering test satellites for the Department of Defense as well as scientific satellites for U.S. and international customers at about $12 million to $14 million per launch. Pegasus has launched a number of OSC's own payloads, including the Orbview 2 remote sensing satellite and the initial launch of satellites for OSC's Orbcomm LEO communication satellite constellation. Pegasus has been launched 19 times since its maiden flight in 1990: eight of the standard Pegasus and 11 of the current Pegasus XL. Of these launches, six have been commercial and 13 non-commercial.

Ten Pegasus launches are planned over the next two years. These include six commercial launches, two of which are Orbcomm satellites (in sets of eight), three scientific, and one communication satellite. Four non-commercial government launches are also planned, carrying three scientific and one experimental payload.

Pegasus has had a historical maximum launch rate of five per year in 1997 and industry analysts consider the maximum expected Pegasus build and launch rate to be about eight per year.[4]

Taurus

Orbital Sciences Corporation's Taurus is essentially a three-stage solid propellant Pegasus vehicle stacked on a solid propellant Thiokol Castor 120 solid rocket motor (called stage 0). Its LEO capacity is 3,100 lb.

Taurus was successfully launched on March 13, 1994 and deployed the ARPAsat satellite as well as the STEP 0/TAOS 1 payload for the Department of Defense. This vehicle differed from the current Taurus configuration; it used a Peacekeeper ICBM first stage instead of the Thiokol Castor 120 stage, which will be used by future Taurus vehicles.

Taurus is expected to make two commercial and two non-commercial launches before the end of

[3] "United States/LAUNCHERS," *Jane's Space Directory, 1995-1996*, pg. 275.

[4] "United States/LAUNCHERS," *Jane's Space Directory, 1996-1997*, pg. 262.

1999. The first commercial launch will take place early in 1998. This launch will carry the Geosat Follow-On (GFO) spacecraft, along with two Orbcomm satellites and the second Celestis funerary payload. The second commercial launch will carry the Korean Kompsat remote sensing payload in 1999.

Non-commercial payloads manifested for Taurus include the STEX 1 and TSX 5 satellites for the Department of Defense. Both of these are intended for launch in 1998. STEX 1, or the Sensor Technology Experiment, will demonstrate radiation measurement technology. TSX 5, the Tri-Service Experiment Mission, will support technology development for the Ballistic Missile Defense Organization.

A Taurus launch costs approximately $18 million to $20 million.

INTERNATIONAL VEHICLES

Following its first commercial Pegasus launch in 1993, the United States has made eight of nine small commercial launches worldwide. Until the 1997 launch of EarlyBird on a START-1 launch vehicle, the United States was the only nation whose firms provided commercial small launch services. With the former Soviet launch industry now providing commercial services, the United States no longer holds this exclusive position. The commercial small launch vehicle market became truly international on December 24, 1997 with the successful launch of a Russian START-1 vehicle.

Other emerging players in the small launch vehicle market include Brazil and possibly Israel. Although the first flight of the Brazilian VLS ended in failure in 1997, it will be offered commercially some time in the next few years. The Israeli Next vehicle, based on the Shavit, may launch payloads commercially if an international partner can be found to provide a launch site outside of Israel, which is limited by overflight restrictions.

Meanwhile, other countries, such as China and India, have begun offering commercial services on medium launch vehicles which compete with the small launch vehicle market. China's Long March 2C, for example, successfully placed two Iridium satellites in orbit on December 8, 1997. The Chinese Long March 2C is a medium lift launch vehicle by FAA's definition but is small enough to compete directly against small-class vehicles. India's PSLV, another medium-class vehicle, will carry a South Korean satellite as a secondary payload in the third quarter of 1998.

Russia

Russia currently markets three small launch vehicles to both commercial and non-commercial customers: Cosmos, Rockot, and START. Russia is the largest provider of commercial small launch vehicles outside of the United States. It is the only other country, besides the United States, to have conducted a commercial small launch. This launch took place on December 24, 1997 from the Russia launch site at Svobodny when EarthWatch, Inc.'s EarlyBird remote sensing satellite was deployed on the START-1 launch vehicle. Russia has also launched several foreign small satellites as secondary payloads on other Russian vehicles.

Cosmos

The Cosmos launch vehicle is a two-stage liquid fueled launch vehicle with a LEO capacity of 3,100 lb.

Cosmos has been launched over 400 times since its introduction in 1964. Two developmental flights of the Faisat satellite system, Faisat 1 and Faisat 2v, were launched aboard Cosmos vehicles in 1995 and 1997.[5] Cosmos launch services are now sold in the United States through Cosmos USA, a partnership between Assured Space Access of Arlington, Virginia, and EDB Polyot of Omsk, Russia.

In May 1996, Final Analysis, Inc. announced it would buy four Cosmos launches to deploy 26 operational satellites, plus spares. The first dedicated commercial launch of the Cosmos vehicle will be in 1999 when it will carry the first seven Faisat satellites. The entire constellation will be deployed by 2000. A Cosmos launch is reported to cost between $10 million and $14 million.

Rockot

Rockot is a three-stage liquid-fueled vehicle based on the SS-19 ICBM with a LEO capacity of 4,100 lb. Daimler Benz of Bremen, Germany and Russian Rockot manufacturer Khrunichev formed a joint venture known as Eurocket in March 1995 to market a commercial variant of the vehicle.

Rockot made its first orbital launch in December 1994 when it launched Radio Rosto, an amateur radio satellite, for the Russian Defense, Sports, and Technical Organization.

The next launch of Rockot is expected in 1998, carrying the UoSat-12 satellite for Surrey Satellite and Technology on a non-commercial launch. The launch will be a development flight for a new minisat satellite platform and which will carry collaborative payloads from Nanyang Technological University in Singapore and the European Space Agency.[6] The E-sat data-messaging system is a "little-LEO" constellation of six 210 kg satellites planned by Echostar and DBS Industries. The system is currently undergoing mass trade-off studies and will be deployed on either two Rockot launches (carrying three satellites each) or three Rockot launches (of two satellites each) beginning in late 1998. The launch of this little LEO system will mark the first dedicated commercial launch of the Rockot.

START

The START launch vehicle family consists of the four-stage START-1 with a LEO capacity of 790 lb. and the five-stage START with a LEO capacity of 1,543 lb. These vehicles are based on the solid-fuel SS-20 and SS-25 ballistic missiles.

START-1 first flew on March 25, 1993 and placed a small test satellite in orbit. The first flight of the five-stage START ended in failure on March 28, 1995, resulting in the loss of Israel's Gurwin satellite and Unamsat for the Autonomous University of Mexico. The second flight of the START-1 successfully launched Zeya on March 4, 1997, a small experimental satellite carrying a communications and geodesy payload. The Zeya launch was the first launch from Russia's new far Eastern launch site at Svobodny.

The most recent and perhaps most significant flight of a START-1 launch vehicle was EarthWatch's EarlyBird remote sensing spacecraft on December 24, 1997. This flight was the first dedicated commercial launch of a non-U.S. small launch vehicle.

[5] "Final Analysis/VITA Launch Falls Victim to Red Tape," *Satellite News*, April 28, 1997, p. 1.

[6] Surrey Small Satellite Homepage (http://www.ee.surrey.ac.uk/CSER/UOSAT/SSHP/future_minis.html)

The next commercial flight is expected to be the Swedish Odin satellite in 1998. A LEO store-and-forward system known as Courier has been proposed by START manufacturer MTT and STC Complex and would be launched sometime after 1999 if the program is carried through. STC Complex of Russia is handling all contracts for the START vehicle.

A deal between Akjuit Aerospace and STC Complex, signed in October 1996, will allow START launches from Canada beginning in late 1998. The new commercial launch site, called SpacePort Canada, is located near Churchill, Manitoba on the shore of Hudson Bay. The agreement will provide a turn-key launch service package aimed at servicing the small satellite industry and will be ideal for launching into polar, high-inclination, and sun-synchronous orbits.[7]

China

China is active in the commercial LEO market using the Long March 2C. Although defined as a medium-lift launch vehicle, it competes in the small payload launch market because of its rather low capacity (7,040 pounds to LEO). On September 1, 1997, a Chinese Long March 2C was used to launch two, inert "Mass Frequency Simulators" to test the vehicle's capability to launch Iridium satellites. The Long March 2C later successfully orbited two actual Iridium satellites on December 8, 1997. Several additional Long March 2C Iridium launches are planned for 1998. To date, no other commercial payloads are known to be manifested for Long March 2C, which costs about $15 million to $20 million per launch.

Brazil

Brazil has spent many years developing its own orbital launch capability, which culminated last year in the first launch attempt of the Veiculo Lancador de Satellites (VLS). VLS has a LEO capacity of 440 lb. It failed in its first launch attempt on November 2, 1997 when one of its four solid rocket motors failed to ignite. Developed from technology used in Brazil's Sonda sounding rockets, VLS launch vehicles use the launch complex at Alcântara, Brazil. Located less than three degrees south of the equator, Alcântara is an excellent site for equatorial launches. Brazil plans to launch one VLS rocket per year for the next several years and intends to eventually sell VLS launch services commercially. The recent inaugural flight of the VLS was a non-commercial launch and reportedly cost about $6.5 million.

India

India developed its Polar Satellite Launch Vehicle (PSLV) to launch its series of earth resource remote sensing satellites. The PSLV is technically a medium-lift launch vehicle but could, in principal, be used commercially for a variety of commercial LEO missions. It can put 6,400 lb. into LEO. The PSLV has been launched four times since 1993, failing on its first launch attempt due to a problem with the separation of the second stage. The PSLV flew successfully in 1994 and 1996 but, on September 29, 1997, it placed the IRS 1D satellite into a lower-than intended orbit (onboard propulsion managed to raise the orbit of IRS 1D to the intended location). There are five more PSLV launches currently planned by the Indian government at the rate of about one per year. The unit cost of a PSLV vehicle is reported to be between $11 million and

[7] "Spaceport Deal Signed/Canadians Will Launch Russian START Rockets," *Space News*, October 14, 1996, p. 1.

$12 million. The next launch, in 1998, is expected to carry a small South Korean satellite as a secondary payload with the IRS P4 satellite.[8] No dedicated commercial launches are planned at this time.

Israel

Israel will offer commercial launch services on Next, an upgraded version of its domestic Shavit launch vehicle. Shavit, built by Israeli Aircraft Industries, has conducted three non-commercial launches to date. These launches placed three Israeli Offeq remote sensing satellites in orbit in 1988, 1990, and 1995. When launched from Israel's domestic launch site in the Negev Desert, Shavit is constrained in terms of orbital inclination because of overflight restrictions imposed by neighboring Arab countries. It has a LEO capacity of 350 lb.

Israeli Aircraft Industries has been trying to get permission to use the Wallops Island, Virginia launch site for the Next vehicle. TRW had campaigned for the use of Next to launch the TSX 5 satellite (now scheduled to be launched on Taurus). If the Israelis are successful in finding an international launch site, Next could join the commercial launch market.[9]

Reusable Small Launch Vehicle Concepts

There are currently a number of different reusable launch vehicle (RLV) systems under development by private industry. They are mostly focused on the emerging market for the replacement of satellite in the new LEO telecommunications constellations. The combination of a large potential market and relatively small satellites at low orbits combine to make this an attractive point of entry for new launch systems.

General concepts range from the launch of satellites from a vehicle in a suborbital ballistic trajectory, exemplified by the Rocketplane Pathfinder and Eclipse concepts, to Kistler's design for a relatively conventional but fully-reusable two-stage launch vehicle. Other ideas include the one-stage Roton vehicle that will autogyro back to its launch site. Several of the commercial RLVs in development plan to make their first flights within the next two years, including Kistler's K-1, Kelly Space & Technology's Eclipse, and Rotary Rocket Company's Roton. More specific descriptions of some of these RLV concepts follow, although these do not constitute an exhaustive listing of all current private RLV efforts.

Pioneer Rocketplane's Pathfinder

Drawing on the heritage of the proposed Black Horse military spaceplane of 1993, Pathfinder was proposed by Pioneer Rocketplane of Lakewood, Colorado as a potential design for the X-34. While not selected for the X-34 contract, Pioneer Rocketplane has nevertheless continued development of the Pathfinder vehicle as a commercial concept. In June 1997, NASA awarded one of four $2 million contracts to Pioneer Rocketplane for the Pathfinder. These awards were conducted under the Bantam program, which is intended to develop preliminary designs and conduct wind tunnel tests for concepts to launch small satellites.[10]

[8] Florida Today SpaceOnline (http://www.flatoday.com/space/today/index.htm), September 29, 1997.

[9] "Long Way From Home," *Aviation Week*, February 3, 1997, p.21.

[10] The other three awards went to Universal Space Lines, Inc. of Newport Beach, Summa Technology, Inc. of Huntsville, and Aerojet-General Corp. of Sacramento.

Using in-air fueling, the Pathfinder rocketplane would take on liquid oxygen (LOX) to power several Russian-designed RD-120 engines and then fly to an altitude of 130 km to deploy its payload with an expendable upper stage. Pioneer Rocketplane envisions using Pathfinder as a fast package delivery system or as a vehicle to carry passengers to the edge of space as tourists. The liquid oxygen in-air fueling systems remains the largest technical challenge for their spaceplane, and Pioneer Rocketplane expects it will require about $100 million in investment to develop Pathfinder.[11]

Kelly Space and Technology's Eclipse

Kelly Space and Technology (KST) is developing a family of tow-launched suborbital rocketplanes which would place satellites into orbit using an expendable upper stage. In October 1996, Motorola signed a contract to launch 20 Iridium satellites in ten launches on an as-needed basis, beginning possibly as early as 1999.[12] Three versions of the Eclipse vehicle are planned. In order of capacity from smallest to largest they are: the Sprint, the Express, and the Astroliner. The Sprint will launch only suborbital payloads, while the Express will launch suborbital and microsat orbital missions. The Astroliner would be capable of launching small payloads into LEO. KST is currently conducting ground and flight tests of the Eclipse tow-launch technique using modified U.S. Air Force supplied QF-106 aircraft, along with the USAF Flight Test Center-supplied C-141A tow aircraft at Edwards Air Force Base.

Kistler Aerospace Corporation's K-1

Kistler Aerospace Corporation is developing the K-1, a two-stage fully reusable launch vehicle. It will be a vertical take-off vehicle much like traditional ELVs, but both stages are recovered following air-bag landings. Initial test flights of the K-1 are scheduled for 1998. Kistler plans to offer its K-1 vehicle for $17 million per launch. In August 1997, the U.S. Department of Energy signed an agreement with the Nevada Test Site Development Corporation that will allow Kistler to develop launch operations at that site. Kistler also plans to construct a launch facility at the Woomera site in northern Australia for both test and launch operations.

Rotary Rocket Company's Roton-C

The current design of the Roton was unveiled at the Cheap Access To Space (CATS) Symposium in July 1997. Rotary Rocket plans to use a vertical take-off-and-landing vehicle utilizing a rocket powered ascent and a helicopter-like, unpowered rotor for the descent and landing. The Roton-C concept is based on using centrifugal pumping of propellant by spinning the combustion chambers and using a rotor to land the vehicle instead of engine thrust, parachutes, or fixed wings. Earlier Roton concepts would have employed the rotors during the ascent as well. The first test flights are planned for 1999, with operations beginning in 2000. Rotary Rocket Company will initially offer launch services themselves but hopes to build a fleet of vehicles to be sold to other companies to provide launch, cargo delivery, and space tourism services. The company is still seeking investors after an initial round of fundraising raised about $6 million.[13]

[11] Pioneer Rocketplane *Initial Product/Design* (http://www.rocketplane.com/inprod.htm)

[12] "Motorola Signs Up For Eclipse Launcher," *Space News*, October 7, 1996, p. 1.

[13] Rotary Rocket Company (http://www.rotaryrocket.com)

UNITED STATES GOVERNMENT RLV EFFORTS

The U.S. government is also sponsoring technology development for reusable vehicles through the X-33 and X-34 programs as well as a number of advanced concepts efforts.

The X-33, built by Lockheed Martin, is intended to demonstrate the feasibility of various RLV technologies. It is also intended to enable the private development of a commercial RLV. This vehicle would most likely be the proposed Lockheed Martin VentureStar reusable heavy launch vehicle. It is hoped that such a vehicle could perform many of the missions the space shuttle performs today, including carrying humans into space.

The X-34 will serve as a testbed for various RLV technologies to be used on the X-33. Built by Orbital Sciences Corporation, it is intended to reach speeds up to Mach 8 and altitudes of 80 km. A second X-34 vehicle was recently ordered to reduce the risks to the program in case of the loss of a vehicle.

Other NASA efforts include the Future X program and the X-38/Crew Return Vehicle (CRV). The Future X program deals with aspects of low cost access to space not covered by the X-33 and X-34 programs, and the X-38/CRV is intended to develop a "lifeboat" for the International Space Station. As such, the X-38 is not designed for a crewed launch but will certainly be able to return crews to the Earth.

Another U.S. Government RLV development program is the Military Spaceplane. This program is intended to provide quick access to space to perform a variety of military missions in the second quarter of the next century.