REUSABLE LAUNCH VEHICLE PROGRAMS AND CONCEPTS

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Introduction

This report examines reusable launch vehicles (RLVs) currently proposed for government, commercial, and public uses. The term "reusable launch vehicle" may refer to several different levels of reuse. Some vehicle concepts are fully reusable (that is, the vehicle launches and lands without jettisoning any stages). Others have one stage that is reusable in combination with other stages that are expendable. The table and text below describe different levels of launch vehicle reusability, from most reusable to least reusable.

Full Reusability – Full reusability implies that the vehicle launches, carries a payload to orbit, and returns to Earth with the vehicle (or vehicle stages) intact and without the assistance of any expendable stages. Single-stage-to-orbit (SSTO) vehicle concepts fall into this category, as do the two-stage-to-orbit (TSTO) concepts in which both the orbital vehicle and a booster vehicle fly back to Earth for reuse (many such designs were originally proposed for the Space Shuttle, and several others are currently under study).

Level of Reusability	Examples
Full Reusability	VentureStar, Original Space Shuttle designs
Full Reusability of One Stage, Partial Reusability of Another Stage	Space Shuttle fleet, Buran/Energia
Full Reusability of One Stage, Expendable Other Stages	Pegasus, HOPE spaceplane, Ariane 5 with Crew Transfer Vehicle
Partial Reusability of One Stage	ALS
No Reusability	ELVs

Full Reusability of One Stage, Partial Reusability of Another Stage – Vehicles in this category have one fully-reusable component, and another stage or stages that are partially reusable. The United States' Space Shuttles are good examples of this type of vehicle, as the orbiters are reusable, and components of the boost stages are recovered for refurbishment and reuse.

Full Reusability of One Stage, Expendable Other Stages – These types of vehicles have one stage (either the booster or orbiter) that is reused and other stages that are expendable. The Pegasus launch system, for example, relies on a reusable atmospheric aircraft to carry an expendable rocket launch vehicle to altitude.

Partial Reusability of One Stage – Components of at least one stage of these mostly-expendable vehicles are recovered for future use. An historical example of this concept is the Advanced Launch System (ALS) examined in 1980s and 1990s space launch studies. The proposed ALS designs would recover only the avionics and propulsion packages from vehicles since these key pieces were the most expensive.

No Reusability – Today's expendable launch vehicles such as Atlas, Delta, and Proton have no reusable components.

Another element of a vehicle's reusability is whether components must be overhauled or replaced. A base vehicle may be designed to fly multiple times, but still may have various components and systems that only last one flight or require replacement before the end of the vehicle's expected lifetime. For example, the Space Shuttle fleet requires overhaul of the thermal protection system on each orbiter following each flight.

This report discusses current RLV concepts that employ at least one fully-reusable stage. The reusability of specific vehicle components is not addressed in this report. A matrix containing the design and performance characteristics of each concept accompanies this report.

Overview of RLV Development Program Areas

Reusable launch vehicles (RLVs) present the opportunity to reduce the cost of launches and to provide capabilities that are not now available. It is expected that because of lower operations costs and the reduced cost of building a few reusable vehicles rather than many expendable ones, RLVs eventually may be able to reduce launch costs by as much as an order of magnitude from what they are today. Thanks to these lower costs and because of RLVs re-entry capabilities, these vehicles also may be able to offer a new range of services, such as retrieval of satellites from orbit, rapid passenger or package services to many points of the globe, and tourism services that may carry civilians into space for entertainment.

Over the last five decades, space agencies and aerospace companies worldwide have studied the potential use of RLVs for routine launch operations. RLV designs range from partial to full reusability, and employ various types of propulsion, takeoff, and landing methods. RLVs can use single or multiple stages to reach orbit. TSTO vehicles, using a reusable hypersonic aircraft as the booster and a smaller orbiter to attain orbit, are among the most common RLV concepts. SSTO vehicles present challenges in terms of weight requirements, materials, and propulsion systems that have only recently come to be considered achievable. RLVs have been proposed to launch vertically from launch pads, horizontally from conventional airports, or from towed or air-dropped configurations. Landing horizontally, vertically, or using other means such as parachutes, parafoils, rotors, or water landings have also been considered. The takeoff and landing concepts for a vehicle are integral to the design characteristics of the vehicle and the potential payload it can carry.

RLVs as workhorse launch vehicles have yet to appear, however, for several reasons. The primary reason for the emphasis on expendable launch vehicles (ELVs) instead of RLVs has historically been the higher up-front development costs of RLV designs. In order to field fully-reusable launch vehicles, reusable components and operations techniques must be developed along with the vehicle design. Although construction of RLVs has been possible, governments and commercial companies have been reluctant to provide the funding required to build RLVs that have higher initial costs, but that would reduce operating costs in the long-term. When the designs for the Space Shuttle fleet were first considered, fully-reusable concepts were introduced, and the original selected design was to have two reusable stages. Budgetary pressures, however, molded the vehicle into the partially-reusable system used today.

The materials and designs to construct TSTO RLVs have been available for 35 years, but innovations are still required to develop a SSTO vehicle that can transport payloads to orbit at low costs. Advances in propulsion and structural technology (such as new lightweight composite materials) have been made over the last few decades that are enabling the development of SSTO vehicles. SSTO vehicle technologies may be validated in the next few years with the testing of NASA’s X-33 and X-34 vehicles and with the development of commercial SSTO designs such as the Roton-C. Developments that will be demonstrated by the X-33 will include load-bearing fuel tanks and composite structures. Both the X-33 and Roton plan to use aerospike engines (the aerospike design has existed for decades it has yet to be fully flight tested).

Today there are several drivers that are pushing RLV development forward. The desire to reduce launch costs in the commercial and government markets is greater than ever. The growth in the number of proposed LEO satellite constellations for telecommunication applications has produced demand for low-cost launches, encouraging entrepreneurial aerospace companies to develop commercial RLVs to serve this market.

RLV designs for space tourism applications have been seriously proposed in the last few years. The X PRIZE℠ competition is encouraging construction of passenger-carrying sub-orbital RLVs by over a dozen start-up companies by offering a $10 million prize to the first vehicle to demonstrate the capability to carry 3 people to a 100 km sub-orbital altitude and repeat the flight within 2 weeks.

Government programs are also a key source of RLV development. NASA's current X-33 and X-34 RLV prototype and technology development programs grew out of a series of studies examining the next step following the Space Shuttle program. In 1985, NASA and the Department of Defense were directed by the President to devise a common plan to develop space transportation systems beyond the Space Shuttle. The resulting Space Transportation Architecture Study was focused on meeting civil and military launch needs, and endorsed examining air-breathing propulsion technologies, TSTO systems, and solid rocket boosters.

At the same time, NASA and DoD were collaborating on a much more ambitious vision of the future of space transportation. The National Aerospace Plane (NASP) program began in the early 1980s, with the goal of making a giant technological leap forward to produce a horizontal takeoff and landing SSTO vehicle powered by both airbreathing and rocket propulsion. It was eventually determined that the technological advancement NASP required could not be completed in a reasonable time frame, and by the early 1990s the program was dispersed into smaller technology development programs that are still ongoing.

In the early 1990s NASA undertook the Access to Space Study to examine options for future launch systems. Three options were presented, including upgrades to the Space Shuttle such as a cargo variant or liquid-fueled boosters, new ELV and RLV launch systems with only minor advancements in technology, and new RLV development using advanced technologies.

In 1994, Congress directed DoD to undertake another space launch study. This study, which resulted in the "Space Launch Modernization Plan," or the "Moorman report," developed a range of options for DoD launcher development, eventually leading DoD to focus on developing the Evolved Expendable Launch Vehicle (EELV) to meet its launch requirements, while leaving RLV development to NASA. Later that year, NASA chose to implement the third option of the Access to Space Study, to develop all-new RLV vehicles to meet future needs, while at the same time, DoD decided to develop EELV. This policy was formalized in the National Space

Transportation Policy signed by the President in 1994. NASA's exploration of tall new RLVs has grown into the X-33 and X-34 RLV programs of today.

In addition to the government and commercial RLV programs in the United States, RLVs are under development by other major space agencies such as the European Space Agency (ESA) and Japan's space agency (NASDA), and by private firms outside the United States as well.

Commercial Launch Programs

Program	Developer	Reusability Level
heavy lift launch vehicle (unnamed)	Advent Launch Services	Fully Reusable
Sprint	Kelly Space and Technology Inc.	Full Reusability of One Stage, Expendable Other Stages
Express	Kelly Space and Technology Inc.	Full Reusability of One Stage, Expendable Other Stages
Astroliner	Kelly Space and Technology Inc.	Full Reusability of One Stage, Expendable Other Stages
K-1	Kistler Aerospace Corporation	Fully Reusable
Pathfinder spaceplane	Pioneer Rocketplane	Full Reusability of One Stage, Expendable Other Stages
Roton-C	Rotary Rocket Company	Fully Reusable
Space Cruiser System	Vela Technology Development	Fully Reusable
Space Shuttle	United Space Alliance	Full Reusability of One Stage, Partial Reusability of Another Stage
Space Van/Bantam Van	Third Millennium Aerospace	Fully Reusable
Spacecub	David L. Burkhead	Fully Reusable

Satellite operators and manufacturers have been vocal in their desire to reduce the cost of launching satellites. Several companies have begun to develop commercial RLVs intended to decrease the cost of launch by as much as an order of magnitude. Many of these companies hope to generate revenue by launching satellites for the recent flurry of proposals for large constellations of LEO satellites for communication applications. These vehicles may also foster new markets such as space tourism. Unwilling to wait for NASA's RLV program to validate new technologies to develop a completely new type of spacecraft, these companies are focusing on using existing technologies, materials, and components to build their vehicles. Some of these companies are also focused on space tourism and other potential new markets, instead of, or in addition to, offering payload launch services.

United States Government Programs

Program	Developer	Reusability Level
Clipper Graham (DC-XA)	McDonnell Douglas Space Division	Fully Reusable
X-33	Lockheed Martin	Fully Reusable
X-34	Orbital Sciences Corporation	Fully Reusable
Future X	NASA Marshall Space Flight Center	TBD
X-38	Johnson Space Flight Center, Scaled Composites	Full Reusability of One Stage, Expendable Other Stages
Military spaceplane	USAF, Boeing, Lockheed Martin	Fully Reusable

NASA's Space Shuttle has been the most prominent RLV in the world since its introduction in 1981. The design phase for the Shuttle began in the 1960s, when RLV concepts that had been developed as early as the 1950s were proposed. The United States government is continuing RLV design and development to supplement and eventually replace the Space Shuttle.

NASA began its current RLV technology development programs by soliciting industry proposals for the X-33 and X-34 RLV demonstrators. At about the same time, NASA took over testing of the a vertical take-off and landing demonstration vehicle, the DC-X (Delta Clipper-Experimental) from the military. The original DC-X acted as a testbed for RLV materials, technologies, and operations, and the X-34 will perform a similar mission. In contrast, the X-33 program seeks to integrate RLV technologies into a sub-orbital demonstrator, which is envisioned to foster commercial development of a full-scale orbital RLV. Another NASA X-vehicle program is developing the X-38 demonstrator vehicle as a prototype for a crew return vehicle for the International Space Station.

Following the X-33 and X-34 programs, NASA plans to continue the development of RLV technologies with the "Future X" program that will result in a series of X-vehicles—experimental demonstrators. The Future X program is divided into two classes of vehicles, Trailblazer and Pathfinder. Trailblazer vehicles, like the X-33, will act as integrated technology demonstrators. Pathfinder vehicles, like the X-34, are low-cost testbeds designed to validate specific technologies and applications. Overall, new RLV technologies and systems will be studied under a three-tiered implementation process. The first tier consists of the Advanced Space Transportation Program (ASTP), which develops core RLV technologies and conducts ground tests. The second tier consists of flight tests of technologies validated in the first tier through Pathfinder vehicles. The third tier consists of a Trailblazer testbed RLV using a combination of technologies under development.[1]

NASA has also been conducting the Highly Reusable Space Transportation (HRST) study since 1995 in order to plot RLV development strategy beyond the near term. HRST includes NASA centers, aerospace firms, and engineering universities in developing RLV concepts using advanced technologies and operating methods. While not intended to proceed to a design phase, these concepts have helped NASA to determine what technologies to explore and develop for future RLV programs by providing input to the ASTP and Future X programs.

The United States Air Force, after having completing testing of the Clipper Graham (DC-X) vehicle in 1995, is also continuing to develop some RLV concepts. The Air Force is currently testing a subscale model of a reusable "Space Maneuver Vehicle" (SMV, or mini-spaceplane) for orbital insertion of payloads and on-orbit applications. The SMV may be used with a reusable hypersonic booster. The Air Force has awarded contracts to Lockheed Martin and McDonnell Douglas Space Division to develop designs for the booster, but funding for the spaceplane program is uncertain.

International Concepts

Program	Developer	Reusability Level
Ascender	Bristol Spaceplanes Limited	Fully Reusable
HOPE-X	NASDA	Full Reusability of One Stage, Expendable Other Stages
Kankoh-Maru	Japanese Rocket Society	Fully Reusable
Sänger	DASA	Fully Reusable
SSTO spaceplane	National Aerospace Laboratory (Japan)	Fully Reusable
SKYLON	Reaction Engines Limited	Fully Reusable
Spacecab/Spacebus	Bristol Spaceplanes Limited	Fully Reusable

European and Japanese government space programs have also instituted studies of RLVs. In the early 1990s, the European Space Agency (ESA) promoted the Hermes spaceplane to be boosted into space by the Ariane 5 ELV. While this program was canceled in 1992, ESA initiated the Future European Space Transportation Investigation Program (FESTIP) in 1993 to study a spaceplane concept successor to Hermes. Several spaceplane concepts have been under consideration in Europe since the 1980s, and many of these were offered for FESTIP. The first phase of the program, which examined concept design proposals for systems such as vehicle materials and propulsion, ran from 1994 to 1996. The second phase of the program would develop an experimental vehicle, and although ESA has selected a design for FESTIP to study, a decision on whether to proceed with the second phase has been postponed until 2005.[2]

Other RLV designs from European private-sector firms are also seeking support and funding. German and British companies have an established history of RLV concept development, but private funding for designs from these firms has not yet been secured.

The Japanese have studied their own reusable spaceplane concept since the late 1980s. While funding cuts have changed the scope of the program, the HOPE-X crewless spaceplane boosted by a conventional expendable rocket will make its debut in 2001. In addition, the Japanese have long-range plans for the development of a fully reusable single-stage-to-orbit (SSTO) spaceplane by 2010.

Russia is the only other country to have developed a partially-reusable "Space Shuttle-type" vehicle, the Buran. The Buran, which closely resembles the United States Space Shuttles, flew one automated orbital mission in 1988 and has since been retired and mothballed. Over the last few years, reports of development of two RLV programs in Russia have surfaced, but given the financial difficulties in Russia, their development status is uncertain. Russia is reported to be developing the Multi-purpose Aerospace System (MAKS) based on a small spaceplane named Molniya and launched off the back of a modified An-225 aircraft. Another potential RLV program is Orel (or Oryol), which has the goal of developing a SSTO vehicle employing hybrid propulsion systems by 2010.[3]

The X PRIZE℠

Program	Developer	Reusability Level
CAC-1	Advent Launch Services	Fully Reusable
Cosmos Mariner	Dynamica Research	Fully Reusable
X Van	Pan Aero, Inc.	Fully Reusable
Proteus	Burt Rutan, Scaled Composites	Fully Reusable
PA-X2	Rick Fleeter, AeroAstro Inc.	Fully Reusable
Gauchito	Pablo De Leon and Associates	Fully Reusable
Green Arrow	Graham Dorrington	Fully Reusable
Thunderbird	Steven M. Bennett, Starchaser Foundation	Fully Reusable
The Space Tourist	John Bloomer, Discraft Corporation	Fully Reusable
Lucky Seven	Mickey Badgero	Fully Reusable
unnamed	Paul F. Tyron, Helen Tyron	Fully Reusable
unnamed	William Good, Earth Space Transport System Corporation	TBD

In the spirit of the early 20th century aviation prizes, such as the Orteig prize that Charles Lindbergh won for crossing the Atlantic, the X PRIZE℠ Foundation was established in 1994 as an educational, non-profit corporation dedicated to inspiring private, entrepreneurial advancements in space travel. The St. Louis-based X PRIZE℠ Foundation is offering a $10 million prize to the first entrant able to launch a vehicle capable of carrying 3 people to a 100 km suborbital altitude and repeating the flight within two weeks (only one person and ballast for two others are required to actually make the flights). The X PRIZE℠ is offered to help speed along development of space vehicle concepts that will reduce the cost of access to space to allow human spaceflight to become routine.

The X PRIZE℠ competition currently has 16 entrants offering a variety of different RLV concepts. Most are single-stage spaceplane concepts that employ both air-breathing and rocket propulsion. One of the entrants, Burt Rutan, designer of the Voyager aircraft that flew around the world without refueling, announced at the August 1997 Experimental Aircraft Association convention that the “Mothership” component of his Proteus air-launched RLV design will make an atmospheric flight in the second quarter of 1998.

The next four sections provide descriptions of each RLV concept. The concepts are presented in the order of the companion RLV matrix and are divided into the four categories introduced in the previous section: Commercial Launch Programs, United States Government Programs, International Concepts, and the X PRIZE℠. Each description provides information on the operating characteristics of the vehicle, the vehicle design, and the company or companies responsible for the development of the vehicle.

Commercial Launch Programs

Private industry is developing a variety of RLV concepts with plans to begin commercial launch operations around the turn of the century. The vehicles described in this section are in various stages of development. For example, the Kistler K-1 vehicle has significant funding and is undergoing construction for possible testing in 1998, while the Advent heavy lift vehicle is still only a paper concept.

Advent Launch Services – Heavy Lift Launch System

Advent Launch Services has proposed this concept to provide delivery of medium to heavy payloads to LEO. Advent's primary vehicle concept is the CAC-1, which is an entry into the X PRIZE℠ competition (see CAC-1 entry on page 39). Advent's heavy lift launch vehicle, however, is also in the preliminary design phase. [4]

Advent Launch Services is the partnership of long-time NASA engineer Jim Akkerman and Texas businessman Harry Dace. Akkerman has worked at NASA's Johnson Space Center for over 32 years. He has participated in programs such as Gemini, the Space Shuttle, and Apollo, where he worked on the descent engine of the lunar module. According to a February 1997 article in the Houston Chronicle, Akkerman believes that the time is ripe to offer opportunities for cheap public access to space.[5]

Vehicle: Advent heavy lift launch vehicle (currently unnamed)

Developer: Advent Launch Services

First launch: TBA

Number of stages: 2

Possible launch sites: Gulf of Mexico

Markets served: Launch of heavy-class LEO payloads.

Funding: Program funding is not known.

The unpiloted heavy lift launch vehicle will be launched from, and land in, the ocean (Advent, based in Texas, is suggesting the use of Gulf of Mexico waters). The vehicle will be transported to an ocean launch site by ship or barge, where it will be put into the water and tethered to the sea floor in order to launch vertically. The vehicle has two stages powered by multiple lunar descent engines (i.e. engines of the type used on the Apollo moon lander), with both stages making an autonomous horizontal water landing for recovery.[6]

Advent Launch Services is a start-up company. The continued development of the heavy lift launch vehicle will likely depend upon the success of the CAC-1 in attracting space tourism customers (and thus providing Advent with concept validation and funding for future development).

Vehicle: Astroliner (shown above)
Developer: Kelly Space and Technology
First launch: 2001
Number of stages: 3-4 (including towing aircraft)
Possible launch sites: Atlantic City NJ, Vandenberg AFB, White Sands Missile Range
Markets served: Launch of LEO constellation satellites
Funding: Program is seeking funding. Some private funding secured

Vehicle: Express
Developer: Kelly Space and Technology
First launch: 1999
Number of stages: 3 (including towing aircraft)
Possible launch sites: same as Astroliner
Markets served: Launch of suborbital payloads or LEO microsatellites.
Funding: Program is seeking funding.

Kelly Space and Technology – Sprint, Express, & Astroliner

Kelly Space & Technology (KST) is developing a family of reusable launch vehicles based on the patented "Eclipse" tow-launch technique. These launch vehicles will be towed into the air by a modified transport aircraft, where the RLV will be released and proceed on a sub-orbital trajectory under its own power. Two of the designs use expendable upper stages to inject payloads into orbit.

Former TRW colleagues Michael Kelly and Michael Gallo founded KST in 1993 to (in their words) "commercially provide the lowest cost, most reliable, and fastest response access to space without dependence upon government subsidy."[7]

The flagship of the KST fleet will be the **Astroliner**; it will be preceded by the **Sprint** and **Express** vehicles. The **Sprint** is a one-fourth scale version of the Astroliner (the Astroliner will be slightly larger than the Space Shuttle orbiters). The Sprint will use an existing rocket engine to accelerate to a sub-orbital altitude after towing. The Sprint initially will act as a reusable sounding rocket, carrying payloads on sub-orbital missions. Later modifications to the vehicle will allow it to carry an expendable upper stage to deploy suborbital payloads to higher altitude.[8]

The **Express** will be a half-scale version of the Astroliner. The Express vehicle will be able to carry larger sub-orbital payloads and deploy microsatellites to LEO using conventional upper stages.

Vehicle: Sprint
Developer: Kelly Space and Technology
First launch: 1998
Number of stages: 2 (including towing aircraft)
Possible launch sites: same as Astroliner
Markets served: Launch of sounding rockets. Microgravity or other suborbital missions.
Funding: Program has secured private funding.

The **Astroliner**, measuring 38 meters in length, will be powered by a rocket engine such as Rockwell Rocketdyne Division's aerospike or RS-27, NPO's RD-180 or RD-120, or a multiple engine configuration. Following separation from the tow aircraft, the Astroliner ignites its rocket engine(s) and accelerates to a speed of Mach 6.5 and an altitude of 120 km. The nose of the vehicle then opens to release the payload and the upper stages that will lift the payload to orbit. The Astroliner vehicle then returns to the ground under the guidance of its two-person crew.[9] The original Astroliner design called for an unpowered landing, but the current design features wing-mounted jet engines.

The Astroliner will use expendable upper stages, solid or liquid depending upon mission requirements, to carry payloads from the vehicle into LEO, MEO or GTO (the current Astroliner design has very limited GTO capacity). In planning the Astroliner, a tandem configuration of the Thiokol Star 48B and Star 63F upper stages was used as the baseline design for launching a pair of Iridium-sized satellites.[10] Other, more powerful upper stages such as the Star 75, CSD's Orbus 21, and liquid stages are under consideration for launching heavier LEO payloads such as Motorola's Celestri satellites.[11] A larger version of the **Astroliner** is under consideration to offer GTO launches for payloads of up to about 4100 kg.[12]

KST has received a United States patent for its tow-launch concept. KST claims that the tow-launch method allows vehicles to lift off with heavier payloads than an air-dropped vehicle and allows the elimination of the infrastructure required for vertical launch vehicles.[13] KST also claims that it will offer launch prices of about $10 to $15 million (or about $2000 per pound to LEO)[14] and reduced launch insurance rates for Astroliner payloads.

Financing has been obtained to develop and construct the Sprint. A Private Placement is concluding for KST to incrementally fund progress on the Express and Astroliner.[15] Development of the Astroliner is expected to cost about $150 million.[16] Development of KST's family of vehicles was encouraged by a contract signed in October 1996 with Motorola to launch 20 replacement satellites for the Iridium constellation in 10 as-needed launches, possibly as early as 1999.[17] This is a speculative contract, with payment based on Kelly's development of the Astroliner and ability to launch the satellites when desired.

KST currently is conducting ground and flight tests of the Eclipse tow-launch technique using modified QF-106 aircraft (provided by the U.S. Air-Force), and a USAF Flight Test Center-supplied C-141A tow aircraft at Edwards Air Force Base. The Eclipse Experimental Demonstration (EXD) tests are being conducted in cooperation with NASA's Dryden Flight Research Center and the USAF Flight Test Center, under a Small Business Innovation Research program coordinated by the USAF Phillips Laboratory, now known as the Air Force Research Laboratory. KST also received a matching grant from the state of California to conduct research associated with the EXD program. Actual tow testing is being conducted by the Eclipse team from December 1997 to February 1998.

KST has also registered as a competitor in the X PRIZE℠ competition. The Sprint vehicle could meet the X PRIZE℠ criteria, but winning the X PRIZE℠ is not a driver for its design. KST officials have indicated that, should the X PRIZE℠ still be available once the Sprint vehicle's development goals are met, modifications may be made to attempt to claim the prize.[18]

Kistler Aerospace Corporation – K-1

Vehicle: K-1
Developer: Kistler Aerospace Corp.
First launch: 1998
Number of stages: 2
Possible launch sites: Nevada Test Site, Woomera, Australia
Markets served: Deployment of LEO constellations and replacement satellites.
Funding: Program has secured private funding

Kistler Aerospace Corporation (KAC) is developing the K-1 two-stage reusable launch vehicle for commercial launches of LEO payloads. KAC was founded in 1993 by Walter Kistler, whose background includes founding several technology companies, and Bob Citron, the founder of Spacehab Inc. The former head of NASA's manned space program, George Mueller, currently serves as Kistler's CEO.

Space News reported in 1994 that KAC would offer a reusable orbital vehicle boosted by a first stage "launch assist platform," that would be able to carry 2000 pounds to low Earth orbit for about $500 per pound. KAC had originally planned to build a suborbital demonstrator (the K-0), followed by the operational commercial vehicle.[19] The design was refined in 1995 and 1996 to the current TSTO vehicle that will have a payload capacity of 10,000 pounds to LEO and will offer launch prices of about $4800 per pound.[20]

KAC has made significant progress in preparing its vehicle for testing and launch in 1998, perhaps eventually employing a fleet of five K-1 vehicles. KAC signed a $100 million agreement in January 1997 with Space Systems/Loral to provide ten launches aboard the K-1 beginning in late 1999 through early 2002.[21]

The K-1 will launch vertically like conventional ELVs but will use a unique combination of parachutes and air bags to recover its two stages. The vehicle is designed to operate with a small complement of ground personnel and will be transported to the launch site and erected from a mobile transporter truck. The K-1 vehicle will measure about 23 meters high, with a dry mass of about 30,000 kg.

KAC's K-1 vehicle employs off-the-shelf technology and components in its design. The first stage is powered by three LOX/kerosene NK-33 engines. These engines were originally built in the 1960s for the Russian moon mission program and are being provided by GenCorp Aerojet. Following launch and first stage separation, the first stage deploys parachutes and drops to a pre-determined landing area where air bags are deployed beneath the stage to cushion its landing.

The second stage, or orbital vehicle, continues into low Earth orbit where it releases its payload and performs a re-entry burn. The orbital vehicle is powered by a single NK-43 engine, also provided by GenCorp Aerojet. The orbital vehicle also carries LOX/ethanol thrusters for orbital maneuvers. Following payload separation, the orbital vehicle continues on orbit for about 24 hours, after which the LOX/ethanol thrusters fire to de-orbit the vehicle. After atmospheric re-entry, the orbital vehicle also deploys parachutes and air bags, landing at a pre-determined site.

The K-1 vehicle is scheduled for initial test launches in 1998. To date, KAC has made significant progress to meeting this timetable. KAC's subcontractors are producing the major components of the vehicle. Lockheed Martin is building the LOX fuel tanks and Northrop Grumman has been contracted to provide much of the vehicle structure. KAC has signed an agreement with GenCorp Aerojet to be the prime contractor for the K-1 vehicle. Aerojet will import, refurbish, and provide the Russian-made NK-33 and NK-43 engines that will power the first and second stages respectively.[22] Kistler reportedly has over $100 million of the $500 million needed to develop the K-1.[23]

In August 1997, the United States Department of Energy signed an agreement with the Nevada Test Site Development Corp. that will allow Kistler to develop launch operations at the site.[24] Kistler has also decided to construct a launch facility at the Woomera site in northern Australia for both test and launch operations.[25] Kistler is in pre-application processing with the FAA for permission to conduct launches from the Nevada Test Site, with both stages returning to Earth at the NTS as well.

Pioneer Rocketplane – Pathfinder [26]

Vehicle: Pathfinder

Developer: Pioneer Rocketplane

First launch: TBD

Number of stages: 2

Possible launch sites: Wallops Island, Kodiak Island, Vandenberg AFB

Markets served: Launch of small and medium-class LEO payloads. Sounding missions. Spaceplane sales for fast passenger service, fast package delivery, and military missions.

Funding: Funded for $2 million through the NASA Low Cost Boost Technology Program. Has raised $1.2 million in private funding as of Dec. 1997.

The Pathfinder (not to be confused with the Future-X Pathfinder program discussed in the US Government Programs section) tracks its heritage to a military spaceplane concept. The "Black Horse" spaceplane was promoted within the United States Air Force in the early 1990s by Mitchell Burnside Clapp, who developed the concept of aerial propellant transfer to enable horizontal takeoff and landing SSTO spaceplanes. Two demonstration vehicles were planned as stepping stones to the Black Horse, called the Black Foal and the Black Colt. The Black Foal would have demonstrated aspects of the technology and provided proof of concept. The Black Colt would have flown to half orbital velocity and utilized an existing upper stage to put satellites in orbit.

Clapp left the Air Force and co-founded Pioneer Rocketplane in 1996 along with engineer Robert Zubrin, who led the development of the Black Colt concept at Lockheed Martin.[27] Pioneer Rocketplane advanced the concept (renamed the Pathfinder) as a potential design for NASA's X-34 program.

Although the Pathfinder was not selected for the X-34, its proponents elected to continue development. In June 1997, Pioneer Rocketplane was awarded one of four $2 million NASA Low Cost Boost Technology Program contracts to develop detailed preliminary designs and conduct wind-tunnel tests for concepts to launch small satellites. The other three concepts awarded contracts are expendable vehicles (offered by Summa Technology, Inc., Universal Space Lines, and PacAstro). The schedule of the Low Cost Boost Technology Program calls for NASA to select two of these four designs for prototype construction in early 1998,[28] but the future of this program is uncertain. NASA is currently studying options for the program, with a decision expected by mid-1998.

Pathfinder is a spaceplane operated by a crew of two and is powered by both air-breathing jet engines and LOX/kerosene rocket engines. The 23-meter long vehicle takes off horizontally using jet engines but carries only a tiny amount of LOX on-board. While in flight, the Pathfinder meets a tanker aircraft carrying LOX, which fills the LOX tanks of the Pathfinder in a method identical to today's air-to-air refueling. After taking on the LOX, the Pathfinder ignites its RD-120 rocket engine, carrying it to a speed of Mach 12 and an altitude of about 130 km. The vehicle then releases a satellite payload mated to a conventional upper stage from its payload bay. The payload is carried into orbit by the upper stage and the Pathfinder returns to the atmosphere. After deceleration to subsonic speeds, the jet engines are re-started and the Pathfinder lands horizontally.[29]

The Pathfinder vehicle uses primarily existing technology and components. The propulsion system uses proven jet and rocket engines (two Pratt and Whitney F100 jet engines and one kerosene/oxygen-burning RD-120 rocket engine), and the avionics systems are derived from systems produced for the Boeing 777.

Pioneer Rocketplane believes that its vehicles can be used not only for satellite launch but also for worldwide package delivery, passenger service, space tourism, and military missions. Pathfinder would be capable of carrying 6,800 kg of packages and may be modified to carry 40 passengers.[30] Pathfinder is expected to cost about $250 million to develop, and Pioneer Rocketplane is currently seeking investors for the effort, and has already secured commitments for over $1.2 million by December 1997.[31]

The main technical challenge in developing the Pathfinder is the LOX air-to-air transfer system. While airborne refueling technology is tested and proven, airborne transfer of LOX will require unique equipment that has not yet been developed. Pioneer plans to modify a wide-body aircraft such as a 747, DC-10, or L-1011 to act as the tanker.

Vehicle: Roton-C

Developer: Rotary Rocket Company

First launch: 1999

Number of stages: 1

Possible launch sites: TBA

Markets served: Deployment of LEO constellations and replacement satellites. Vehicle sales for a range of space launch services.

Funding: Program has raised $6 million in private funding.

Rotary Rocket Company – Roton-C

Roton-C is the latest design from the Rotary Rocket Company. Rotary Rocket Company is headed by Gary Hudson and Bevin McKinney, who respectively had directed Pacific American Launch Systems and American Rocket Company. A precursor company co-founded by Hudson and McKinney, HMX, Inc., originated the Roton concepts now under development.

The Roton concept has been under development for several years, and the current design (Roton-C, “C” for “cargo”) was introduced at the Cheap Access To Space Symposium in July 1997. The Roton concept is based on using centrifugal pumping of propellant by rotating the engine about the axis of the vehicle and using a rotor to land the vehicle in place of engine thrust, parachutes, or fixed wings. Other Roton concepts under development include vehicles that use rotors not only for landing but for lift-off as well.[32]

The SSTO Roton-C vehicle is designed for vertical takeoff and landing. The 16-meter high Roton-C is powered by a proprietary design Rocketjet aerospike engine that rotates inside the cylindrical vehicle. The rotation feeds the LOX/jet fuel propellants into the combustors at (which are located the periphery of the engine) at high chamber pressure, eliminating the need for turbopumps to feed the engine. Following ascension to LEO, Roton-C will deploy a satellite payload and perform a de-orbit burn. If weather conditions are not favorable at the landing location, the vehicle can remain on-orbit until conditions improve. After atmospheric re-entry, Roton-C will deploy rotors that allow it to land like an autorotating helicopter, with the rotating blades providing braking and control.[33] Roton touches down vertically under the control of the two to three person crew, landing without fuel on-board. The vehicle is designed to be serviced by a small team of ground personnel and is targeting turn-around times between flights of 24 hours or less.[34] The Roton-C also has been designed to be able to return to Earth with the cargo bay fully loaded.

Rotary Rocket Company is currently raising funds for the development of the Roton-C and has contracted with several other firms for component construction. Rotary Rocket Company is developing the propulsion system internally and has contracted with Scaled Composites for design and construction of the airframe.

A first round of fundraising for vehicle development produced $6 million.[35] Rotary Rocket Company recently reached an agreement with Barclays Capital for Barclays to serve as financial advisors and placement agency for an approximately $30 million private equity placement.

Rotary Rocket Company plans to begin flight tests in 1999, with operational capability beginning in 2000. Rotary Rocket company will initially offer launch services but hopes to build a fleet of Roton vehicles that can be sold to other companies that may provide a range of space launch services.

Vela Technology Development – Space Cruiser System

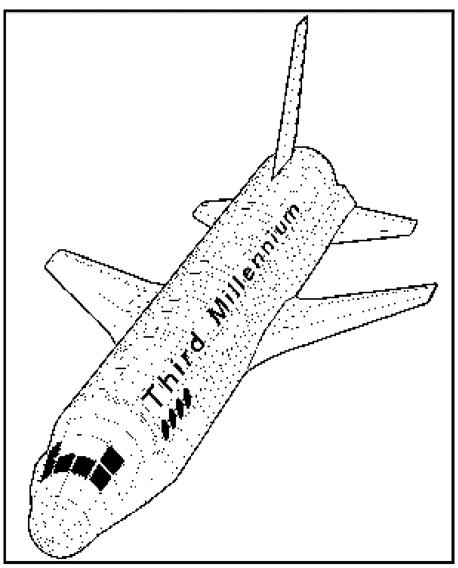
The Space Cruiser System (SCS) vehicle is currently being marketed for space tourism flights beginning in 2001 by Zegrahm Space Voyages, a division of the Zegrahm Expeditions travel company. The SCS vehicle is being designed and developed by Virginia-based Vela Technology Development, Inc. to carry six passengers on a suborbital flight reaching just over 100 km in altitude.[36]

Steven J. Höeser is president of Vela Technology Development. Höeser and all of Vela's technical personnel have extensive NASA, commercial aerospace, or U.S. Air Force space systems experience. The company is planning to use existing technologies to create passenger-carrying vehicles.[37]

Vehicle	Space Cruiser System (second stage spaceplane pictured)
Developer	Vela Technology Development
First launch	2001
Number of stages	2
Possible launch sites	Commercial airports
Markets served	Suborbital space tourism flights.
Funding	Program funding is not known.

SCS is a two-stage horizontal takeoff and landing design that employs both airbreathing and rocket engines. The "Sky Lifter" first stage booster will be piloted by a two-member crew and will be powered by two JT8D/F100-class jet engines. The Sky Lifter will be about 33 meters long, with a dry mass of approximately 10,000 kg. The Sky Lifter will carry the "Space Cruiser" second stage spaceplane underneath. The Space Cruiser will measure about 12 meters long and will have a mass of approximately 8000 kg. The two stages will climb together to about 15 km (50,000 ft.) where the Space Cruiser, carrying two crew and six passengers, separates and will climb to 100 km using its three Nitrous Oxide/Propane-fueled rocket engines. During re-entry into the atmosphere, the Space Cruiser will fire retro rockets to slow descent and then will activate two JT15D-class turbo-jet engines to return to a landing site.[38]

Vela Technology Development plans to build two sets of operational vehicles and plans to initially operate two launches per week.



Third Millennium Aerospace – Space Van/Bantam Van

The Space Van and Bantam Van are the commercial space tourism and satellite launch systems proposed by Third Millennium Aerospace. Third Millennium has plans for both launch services and space tourism services for its vehicles. Third Millennium's founder, Len Cormier, believes that small, low-cost RLVs will provide a better return on investment than the 20 ton capacity SSTO RLV design that NASA envisions.[39]

Third Millennium's space tourism plans call for initial suborbital flights using the Bantam Van. The second phase would use the Space Van to construct an orbiting facility capable of hosting tourists for a one-week stay.

Third Millennium has also promoted several conceptual uses for RLVs outside of space tourism. It has proposed an international consortium, Third Millennium Telecommunications, to pursue an integrated approach to low-cost, high-capability space-based communications based upon the

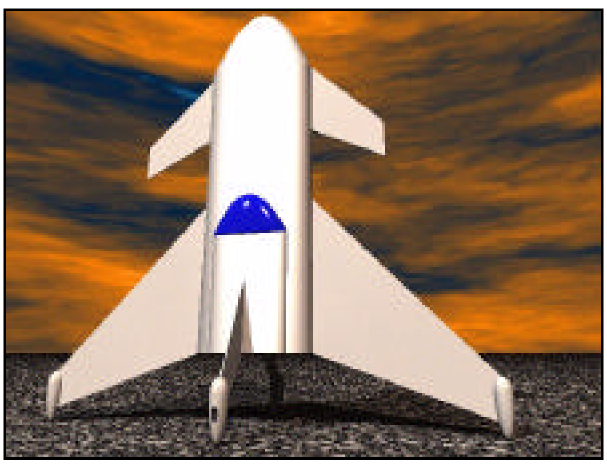
Vehicle: Space Van
Developer: Third Millennium Aerospace
First launch: TBA
Number of stages: 2
Possible launch sites: TBA
Markets served: Orbital space tourism flights. Launch of LEO and GEO satellites. Mining of helium from the moon.
Funding: Program funding is not known.

availability of the Bantam Van launch vehicle. In addition, Third Millennium has expressed interest in using RLVs for space solar power construction, space-based manufacturing, orbital debris removal, and the mining of helium-3 from the lunar surface to provide fuel for spacecraft.

The Space Van is designed to carry 16 passengers plus 3 crew to LEO. A cargo carrying version is also planned. The Space Van would measure about 32 meters long and have a dry mass of about 12,000 kg. Third Millennium is partnered with an organization known as Space Tour, which hopes to raise the approximately $500 million in funding for the construction of the Space Van.[40]

The Space Van would be the upper-stage orbiter of a two stage system. The first stage would consist of a relatively simple reusable booster that carries the Space Van orbiter to about Mach 3 at 30 km. Third Millennium claims that boosting to this altitude and at this speed allows for construction of the booster and design of the orbiter using existing materials and powerplants.[41]

The Bantam Van is a scaled-down version of the Space Van that Third Millennium suggests should be built first in order to provide commercial operations to generate demand and funding for the Space Van. Third Millennium feels that construction of the Bantam Van is currently feasible for a cost of about $75 million. The Bantam Van would use a scaled-up version of the X Van (see entry on page 41) as a first stage booster and would be capable of carrying 400 kg to a 450 km LEO orbit.[42]



Vehicle: Spacecub
Developer: David L. Burkhead
First launch: TBA
Number of stages: 1
Possible launch sites: TBA
Markets served: Personal suborbital space tourism
Funding: Program funding is not known.

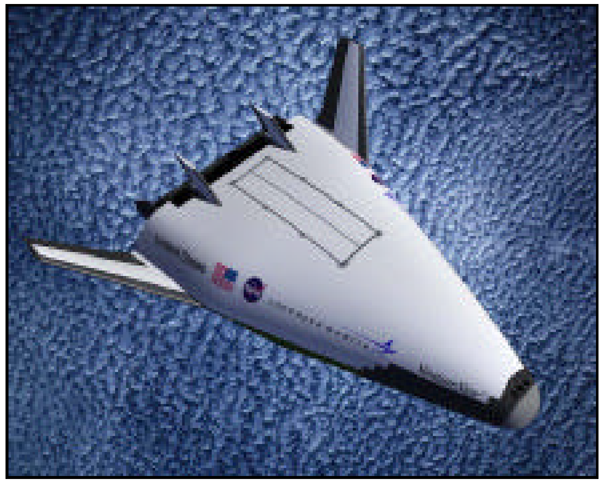
David L. Burkhead – Spacecub[43]

Spacecub is a four-seat vehicle designed for VTOL operations by private individuals. Spacecub has been proposed as a kit vehicle, built by individual hobbyists for suborbital flights. The vehicle has been proposed by aerospace enthusiast David L. Burkhead since 1994.

Spacecub would be a 10-meter long cylindrical vehicle with wings. Propulsion would be provided by four LOX/kerosene rocket engines, giving the vehicle the capability to reach an altitude of 130 km.

Spacecub would launch and land vertically. Following descent from its peak altitude, the vehicle gradually slows and pulls into a glide. After gliding over the landing area and pulling into a vertical position, the vehicle fires its engines to execute a powered touchdown. Spacecub's flight systems could be programmed to provide a range of control capability for the pilot, ranging from fully-automated flight to full manual control.

Lockheed Martin Corporation – VentureStar



Vehicle: VentureStar
Developer: Lockheed Martin Skunk Works
First launch: 2004
Number of stages: 1
Possible launch sites: TBA
Markets served: Launch of heavy-class LEO payloads.
Funding: May be funded by Lockheed Martin as a commercial follow-on to the X-33.

In 1993, Lockheed Skunk Works introduced a concept vehicle using an aerospike engine and a wedge-shaped lifting-body design known as an "aeroballistic rocket" (a VentureStar forerunner), and offered it for the Air Force's planned new vehicle program called "Spacelifter," but Spacelifter was canceled in the wake of the EELV program.

Today's VentureStar resembles the original aeroballistic rocket in the lifting-body design. VentureStar is Lockheed Martin's potential commercial follow-on to the X-33 vehicle being developed for NASA's RLV program (see pages 21-23 for a complete overview of the X-33). The VentureStar vehicle will be similar in design to the X-33 but twice the size and about eight times the launch mass. Development of the VentureStar vehicle is underway in parallel with the X-33, but Lockheed Martin has not yet made a firm decision to proceed with VentureStar construction. Complete development of an operational VentureStar will require significant funds, and Lockheed Martin is examining whether the market will support a return on investment that will make the vehicle feasible.

United States Government Programs

In the 1990s, NASA and the military have made significant strides in RLV development. The DC-X (later the DC-XA and Clipper Graham) was funded by the military in the early 1990s and later by NASA. This vehicle demonstrated RLV materials and operations and paved the way for the current NASA X-33 and X-34 RLV prototype development programs. In addition to the X-33 and X-34 RLV programs, NASA is also participating in a joint effort with the European Space Agency for a crew return/crew transfer vehicle for the Space Station. The US military is continuing its RLV study with the development of military spaceplane concepts.

Vehicle: Clipper Graham (DC-XA)

Developer: McDonnell Douglas Space Division

First launch: 1993

Number of stages: 1

Possible launch sites: White Sands Missile Range

Markets served: Demonstration of VTOL capabilities, RLV materials, and rapid turn-around operations. Possible future development as first stage of the military spaceplane.

Funding: Program is complete.

Clipper Graham (DC-XA) [44]

In the 1950s, McDonnell Douglas advanced a vertical takeoff and landing (VTOL) spaceplane concept,[45] but such a design did not come into development until the Delta Clipper-Experimental (DC-X). In the late 1980s, the Strategic Defense Initiative Organization (SDIO) was exploring launch system options to reduce the cost of launching small payloads (especially for launching an SDI system). The Delta Clipper (DC-X) program was funded under the Phase II Single Stage Rocket Technology program of the SDIO's successor, the Ballistic Missile Defense Organization (BMDO), in 1991. The DC-X demonstrator vehicle was delivered in April 1993, and system and flight testing began immediately. Flight testing involved vertical launches, hovering, vertical landing, and a gradual exploration of different aspects of an actual flight plan.

Military funding for continued DC-X testing, however, was difficult to maintain and flight testing was halted in October 1993. Flight tests resumed in 1994 as BMDO renewed funding and NASA agreed to provide additional funds for the project. A total of eight flight tests were completed by July 1995. Following the eighth test flight, control of the vehicle was transferred to NASA, which directed modifications to the vehicle to test technologies for the RLV program and redesignated the vehicle DC-XA.

Concurrently, a McDonnell Douglas-Boeing team proposed a VTOL concept based on the DC-XA for NASA's X-33 program.

NASA flight testing of the DC-XA (renamed the Clipper Graham in June 1996) produced three successful test flights. On June 7 and June 8, 1996, the Clipper Graham performed two test flights within 26 hours, demonstrating the potential for quick turn-around capability for RLVs. The fourth and final flight test of the vehicle ended disastrously as one of the vehicle's four landing gear legs failed to deploy. The vehicle toppled over on landing and was completely destroyed. The Clipper Graham experimental vehicle measured 11.8 meters in height and had a dry mass of 10,200 kg. A full-scale version would measure 38.5 meters high with a mass of about 46,800 kg.[46]

NASA has since selected Lockheed Martin's X-33 concept for the RLV program. Without further funding, development of a full-scale version of the Clipper Graham is questionable. McDonnell Douglas Space Division (now a subsidiary of Boeing), however, has presented a proposal for the military spaceplane based on the Clipper Graham design (see military spaceplane entry on page 29).

X-33 [47]

Vehicle: X-33

Developer: Lockheed Martin Skunk Works

First launch: 1999

Number of stages: 1

Possible launch sites: TBA

Markets served: Testbed for RLV technologies and operations.

Funding: Project is funded under NASA's RLV Program. NASA will contribute $950 million and Lockheed Martin will contribute $220 million.

Following the National Space Transportation Policy announced in 1994, NASA initiated the RLV program and solicited proposals for the SSTO X-33 experimental demonstrator. NASA's focus on SSTO RLV technology stems from the conclusions of the 1993 Access to Space Study. Based on this study, NASA decided to pursue the development of new SSTO technologies and vehicles.

The X-33 program was initiated to develop a testbed for integrated RLV technologies, paving the way for full-scale development of a reusable launch vehicle that would be contracted for government and private sector use. The X-33 is targeted to reach high hypersonic speeds and demonstrate SSTO and autonomous operations capabilities. NASA has set goals of a routine seven hour turn-around time and a 3.5 hour emergency flight turn-around time. NASA hopes the program will lead to the development of RLVs that will reduce the cost of space launches to at most one quarter of today's prices.

In April 1995, NASA signed cooperative agreements with Lockheed Martin, McDonnell Douglas, and Rockwell International to develop concept designs for the X-33 program. Lockheed Martin offered a vertical takeoff, horizontal landing concept based on the aeroballistic rocket/VentureStar design (see the VentureStar entry on page 19 for background information). Rockwell also offered a vertical takeoff, horizontal landing design, and McDonnell Douglas proposed a VTOL design based on its Clipper Graham vehicle.

On July 2, 1996, NASA selected Lockheed Martin's design. NASA will provide almost $950 million in funding, while Lockheed Martin is expected to contribute $220 million. Payment, however, is based on meeting progress milestones during development.

Lockheed Martin's design is a single stage to orbit (SSTO) vehicle that relies on a lifting body rather than wings. The X-33 will measure about 20 meters in length, with a dry mass of about 28,350 kg. The X-33 vehicle is sometimes referred to as VentureStar, but in this context, we use VentureStar to refer to Lockheed Martin's intended full-scale operational RLV design. The VentureStar vehicle will be similar in design to the X-33 but twice the size and about four times the dry mass. The X-33 and the VentureStar will be powered by linear aerospike engines under development by Rocketdyne that do not use conventional cone-shaped exhaust nozzles but allow the exhaust flow to adjust to changes in atmospheric pressure.

NASA has scheduled completion of the X-33 program by 1999. Fifteen flight tests are planned to cover medium and long-range flights from July to December 1999. The aerospike engine has been undergoing flight testing, and final engine qualification tests are scheduled for late 1998. Rollout of the completed X-33 is scheduled for May 1999.[48]

The X-33 is currently under construction at Lockheed Martin's Skunk Works facility. Although the design was reported to have stability and weight problems during the summer of 1997, the X-33 recently reached two major milestones in the design process. In November 1997, the vehicle passed a critical design review, a key step before actual construction begins. Lockheed Martin continues to attempt to reduce the dry weight of the vehicle and must build a composite material fuel tank for the liquid hydrogen propellant. The top speed of the X-33 will only be Mach 13, rather than the Mach 15 goal originally targeted.[49]

On November 6, 1997, NASA completed the environmental impact statement (EIS) process for the X-33 testing program, which considered issues such as public safety, noise, impacts on general aviation, and effects on biological, natural, and other resources. The 15 test flights of the X-33 will be conducted from the launch site at Haystack Butte on the eastern portion of Edwards Air Force Base, CA, to landing sites at Michael Army Air Field, Dugway Proving Ground, UT, and Malmstrom Air Force Base near Great Falls, MT. Construction crews broke ground on November 14, 1997 for the launch facility at Edwards AFB, with completion expected in one year.[50]

Vehicle: X-34
Developer: Orbital Sciences Corporation
First launch: 1998
Number of stages: 1
Possible launch sites: White Sands Missile Range
Markets served: Testbed for RLV technologies and operations.
Funding: Project is funded for $60 million under NASA's RLV Program.

X-34

Following the implementation of the Space Transportation Policy in August 1994, NASA initiated the X-33 program for a heavy-lift RLV and the X-34 program to develop an RLV for payloads of about 1100 kg. In April 1995, NASA signed an agreement with Orbital Sciences Corporation for the development of the X-34 technology testbed. At this time, Orbital and Rockwell International formed a joint venture known as American Space Lines to develop and operate the X-34. The X-34 program was originally designed to offer the possibility of development into a commercial booster on its own after accomplishing its technology demonstration goals. Flight tests were planned for late 1997, but Orbital, Rockwell, and NASA could not agree what engine to use for the vehicle. The problems with the program apparently were such that NASA terminated the contract with Rockwell and Orbital in February 1996.[51] Other reports contend that Orbital and Rockwell found that the vehicle would not be commercially viable, which resulted in them pulling out of the project.[52]

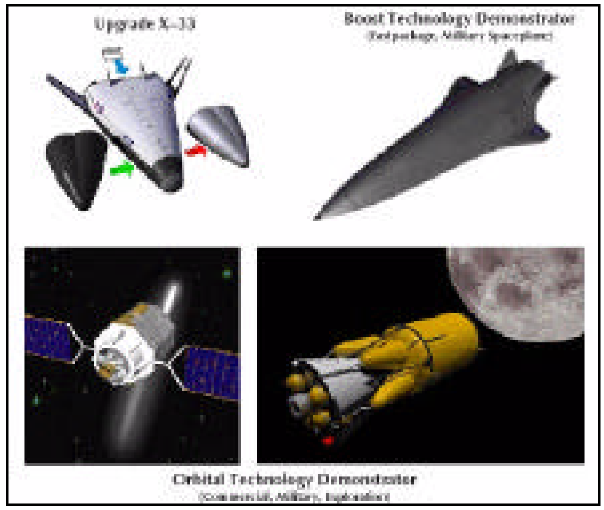
NASA redesigned the X-34 program to use a smaller vehicle to demonstrate key technologies. Following a competition that included nine entries, NASA again awarded Orbital Sciences Corporation a $60 million contract in June 1996 to design, develop, and test the X-34 vehicle.

The X-34 is designed to be a sub-orbital technology testbed vehicle for the RLV program. The goals of the X-34 are to achieve a maximum speed of Mach 8 and to reach altitudes of up to 80 km. Flight testing will focus on RLV operations such as 24 hour turn-around, landing in adverse weather conditions, and safe abort procedures. New technology demonstrations will include composite primary and secondary airframe structures; cryogenic insulation and propulsion system elements; advanced thermal protection systems and materials; and low cost avionics, including differential global positioning and inertial navigation systems. Operations technologies such as integrated vehicle health-monitoring and automated checkout systems also will be validated.[53]

Orbital Sciences' design features a cylindrical body with delta wings. The X-34 will measure 17.7 meters in length and will have a dry mass of 19,500 kg. The vehicle will be launched from an L-1011 carrier aircraft (much like Orbital Sciences' Pegasus expendable launch vehicle). The engine is a new LOX/kerosene rocket engine known as Fastrac, that is designed, developed, and provided by NASA under a separate program. The X-34 design, however, will allow for easy substitution of engines.[54]

In May 1997, the X-34 completed a system design freeze, and flight tests are scheduled to begin in late 1998. Phase 1 of the program calls for two test flights at speeds up to Mach 3.8. Still being considered by NASA is an option for a second phase of the testing program that calls for 25 flights over 12 months, achieving a range of different speeds and operating in a variety of conditions.[55]

Future X Trailblazer Program



Vehicle: Trailblazer-class

Developer: Marshall Space Flight Center in cooperation with private industry

First launch: TBA

Number of stages: TBA

Possible launch sites: TBA

Markets served: Testbeds for RLV technologies and operations. Future X Trailblazer vehicles will act as experimental demonstrators that respond to the mission needs of end users.

Funding: Program is not funded.

Following the award of the X-33 contract, NASA attempted to determine whether to continue creating experimental vehicles, and if so, what future X-vehicles to fund. NASA found it had difficulty choosing among 10 specific candidates and instead decided to develop a framework for the development of X-vehicles. This resulted in the Future X program and its Trailblazer and Pathfinder classes of X-vehicles.[56] New X-vehicles will be developed as technology concepts are presented, as demand for development of a concept is expressed by potential users, and (most importantly) as funding becomes available. New technology concepts will evolve out of the Advanced Space Transportation Program, as discussed in the introduction to this document (see page 6).

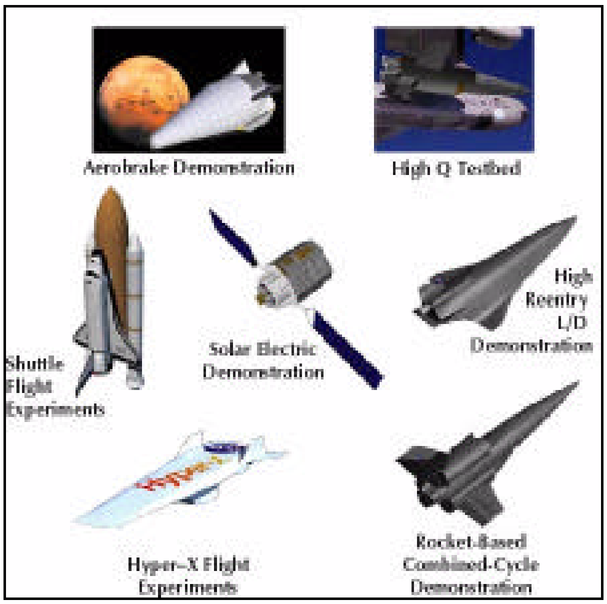
The Future X Trailblazer program will develop technology demonstrator vehicles that will test integrated vehicle systems. The vehicles will validate the viability of complete programs. For example, the X-33 is designed not only to validate technology but also to validate RLV operations such as turn-around time and safe abort procedures. Trailblazer programs respond to mission needs (as the X-33 responds to the need for reduction in space cost access) and will share costs between NASA and other end users.[57]

Currently, there are no funded Trailblazer programs. NASA, however, has identified several vehicle concept types and programs that would be classified under Trailblazer:[58]

Boost Technology Demonstrator—This vehicle would represent a follow-on to the X-33. It would test new technologies and components beyond those used in the X-33 and would be designed for a customer-specific mission. For example, such a demonstrator could be designed to meet military operational requirements, or it could be designed to meet the needs of the commercial package delivery market.

X-33 Upgrade—This program would provide upgrades to the X-33 vehicle beyond the current design. Such upgrades could consist of developing a composite construction LOX fuel tank to replace the current aluminum tank or of improving the performance of the aerospike engine.

Orbital Technology Demonstrator—This program would develop an on-orbit vehicle that could provide commercial capabilities such as transfer of payloads from lower orbits to higher orbits. Other concepts include an on-orbit vehicle for military missions and a vehicle to demonstrate technologies that could be used for planetary exploration.



Future X Pathfinder Program

The Future X Pathfinder program will develop testbed vehicles that focus on validating specific technologies (in contrast to the Trailblazer program, which will develop vehicle prototypes). These vehicles respond to the need to test new technologies and will be low-cost programs that produce vehicles in less than two years. It is intended that the materials and technologies tested under this program will be integrated into the RLVs of the future.[59]

Like the Trailblazer class of vehicles, the Pathfinder class currently has no funded projects. NASA has identified several vehicle and program concepts that could be explored as Pathfinder vehicles, some of which examine RLV-specific technologies:[60]

Aerobrake Demonstration—This project would continue the development of technologies to use planetary atmospheres to reduce spacecraft velocity. Such technologies would have applications in planetary exploration missions. Aerobraking could also be used by a reusable upper stage to reduce its speed to reenter the atmosphere and return to earth.

High Q Testbed—This program would subject a test vehicle to high dynamic pressures to simulate various phases of transatmospheric vehicle operations.

Vehicle: Pathfinder-class

Developer: Marshall Space Flight Center in cooperation with private industry

First launch: TBA

Number of stages: TBA

Possible launch sites: TBA

Markets served: Testbeds for RLV technologies and operations. Future X Pathfinder vehicles will be driven by specific technology developments and provide low-cost validation of these technologies.

Funding: Program is not funded.

Space Shuttle Experiments—This program would continue the use of the Space Shuttle fleet for testing on various materials and concepts. For example, the shuttles have been used in the past to carry payloads that test thermal protection system concepts and materials.

Solar Electric Demonstration—This project would test solar electric propulsion technologies for use in applications such as orbital transfer stages or electric propulsion upper stages.

High Reentry L/D Demonstration—This program would demonstrate new designs for increasing lift to drag ratio, providing increased lift for crossrange operations through aerodynamic improvements instead of added propulsion.

Hyper-X Experiments—This program would provide follow-on testing for the scramjet[61] propulsion technologies currently being explored in the current Hyper-X program (the current Hyper-X vehicle program funded by NASA will explore hypersonic performance of scramjet propulsion).

Rocket-based Combined-Cycle (RBCC) Demonstration—This project would provide flight validation of systems that combine scramjet and rocket propulsion into a single engine. The RBCC concept is currently under design and funded as part of the Advanced Space Transportation Program.

Highly Reusable Space Transportation Program

NASA initiated the Highly Reusable Space Transportation (HRST) program in 1995 to identify new launch vehicle concepts that could produce launch prices of $100-$200 per pound to LEO. The study focused on propulsion and operations concepts as the key drivers to produce high performance and low costs. A variety of RLV concepts submitted by aerospace companies, NASA divisions, and universities were evaluated. These vehicles were based on propulsion systems that used and combined technologies such as advanced LOX/liquid hydrogen engines, scramjets, and combined-cycle engines. Launch assist methods such as hydraulic and electromagnetic catapults were also examined.

In 1997, the HRST study recommended three concepts that could satisfy near-term RLV needs (including advance-propulsion designs employing RBCC and scramjets, and a TSTO lift assist design) and three concepts that could satisfy far-term RLV needs. Significant technology advancement is needed, however, before any of the concept vehicles could proceed with development.

The second phase of the HRST program, recently completed, draws specific technologies from the concepts developed in the first phase. The study recommended technologies in which NASA should invest in order to further future RLV development. These technologies could eventually be the focus of technology development activities in the ASTP and the Future X programs.

X-38/Crew Return Vehicle [62]

The X-38 is a technology demonstration vehicle project of the Johnson Space Flight Center. The X-38 is a prototype for an emergency crew return vehicle (CRV) that will be attached to the International Space Station. The CRV will provide means of returning to earth if an emergency requiring immediate evacuation of the station arises, if an astronaut has a medical emergency requiring immediate treatment on Earth, or if the Space Shuttle fleet is grounded and the astronauts must return to Earth.

Vehicle: X-38/CRV

Developer: Johnson Space Flight Center, Dryden Flight Research Center, Scaled Composites

First launch: 1999

Number of stages: 1 (at least 2 for launch)

Possible launch sites: KSC, Kourou

Markets served: Prototype for International Space Station crew return operations

Funding: Program is funded by NASA for $80 million for two atmospheric and two space test vehicles.

Plans for a CRV have been under consideration since the Space Station was first proposed. Proposals for CRVs have taken on many different forms. At first, use of a Soyuz capsule or the ESA's proposed Hermes spaceplane were considered. In 1989, NASA decided to solicit bids for the construction of an Assured CRV (ACRV), but the program stalled because of the high costs associated with the proposed designs, which would have provided the capability to both send and retrieve crews from the Space Station.

NASA and ESA are currently working together for a common concept to satisfy their Space Station crew transport needs. Rather than focusing solely on an emergency return vehicle, ESA wants to develop a vehicle capable of both launching and returning crew members to and from the station. Although ESA has directed energies toward developing its own crew transfer vehicle (CTV), it has so far committed $34 million to the development of the X-38. CRV development is expected to cost almost $1 billion, with ESA contributing about 30%.[63]

European participation in the program, however, has recently undergone some turmoil, as France decided in October 1997 to terminate its participation in the program. France had been the largest ESA contributor to the program (39% of ESA's CRV funding).[64] While ESA is trying to piece together additional funding for the CRV effort, the German Space Center (DLR) has independently entered into an agreement with NASA to develop body flaps, a nose cone, and other components for a space flight test of the X-38.[65]

The X-38 employs a lifting body design based on a 1970s-vintage X-aircraft (X-24A). Rather than landing in an unassisted glide like the Space Shuttle, the X-38 will deploy a steerable parafoil (similar to a large parachute) that will allow the vehicle to maneuver to a landing site. Two X-38 atmospheric test vehicles have been constructed by Scaled Composites, with parafoils supplied by Pioneer Aerospace. Avionics and control systems were incorporated into the test vehicles at NASA's Dryden Flight Research Center.

Drop tests of the vehicle have been undertaken in 1997, and further testing is scheduled for February 1998. A full de-orbit and landing test following launch from the Space Shuttle is planned for 1999 or 2000. NASA expects that four CRVs will be developed based on the X-38 design at a total cost of about $500 million. A request for proposals for CRV construction is expected to be sent to United States industry in mid-1998, resulting in an operational vehicle by 2002.[66]

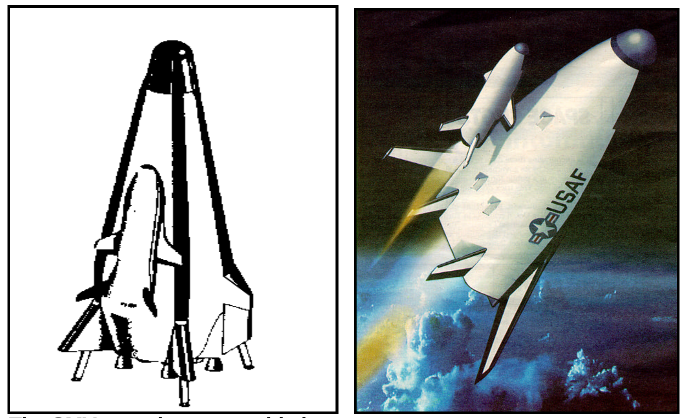
The CRV will employ the same steerable parafoil concept as the X-38. Its control systems would allow it to land within 9 km of a given landing area. Landing will be accomplished by setting down on landing skids, and a backup parachute system will be included as well. The CRV will be able to carry six crew members (although ESA plans for about 3 passengers on the CTV) and would be able to operate free of the Space Station for up to nine hours. Both the X-38 (space test version) and the CRV will use a de-orbit propulsion stage to orient the vehicle for atmospheric re-entry, jettisoning the stage following the maneuver. A full-scale CRV will measure 8.6 meters long with a mass of about 8,200 kg.

Although the X-38 is not designed to be an RLV (that is, it is not intended to be a launch vehicle), it is possible that the eventual design for the CRV (which ESA is planning as the CTV) will be able to attain orbit through launch atop an expendable launch vehicle such as the Ariane 5.[67] While the CRV design has no space maneuvering propulsion system, an orbital transfer vehicle could be used to move it into position at the Space Station, allowing it to carry crews both to and from the station.

Military Spaceplane

In August 1996, the USAF Space Command (AFSPC) approved a "concept of operations" for a spaceplane demonstrator to satisfy USAF space operations needs in the future. An Integrated Concept Team (ICT) was established to develop designs for a multimission vehicle that could perform a variety of orbital and suborbital military missions, such as placing small satellites in low-Earth orbit, conducting surveillance, disabling adversaries' space vehicles, releasing weapons (within the atmosphere) against terrestrial targets, serving as a time-critical communications relay platform, or delivering cargo. The first squadron of military spaceplanes could be operational in the 2030 time frame.[68]

The Space Maneuver Vehicle (SMV) sub-scale testbed



The SMV mated to a reusable booster

Vehicle: Military Spaceplane

Developers: Boeing, Lockheed Martin

First launch: TBA (SMV tests in 1997)

Number of stages: 2

Possible launch sites: TBA

Markets served: Military payload delivery to LEO. Special missions such as satellite orbital transfer

Funding: Program funding is questionable following a presidential veto.

Following a year of study, the AFSPC followed the ITC's recommendation to establish a central spaceplane program office to coordinate the program. Spaceplane research efforts have been funded through "add-on" funds appropriated in 1996.[69]
Through this program, the Air Force is developing a two-stage spaceplane concept. The concept consists of a reusable "mini-spaceplane," or Space Maneuver Vehicle (SMV) that is carried to hypersonic speeds by a suborbital reusable first stage. The SMV is released and accelerates to orbit, where it will be designed to be able to maneuver in space and remain on-orbit for perhaps as long as one year.

Both stages of the spaceplane are under development, but funding is uncertain. In September 1997, the Air Force's Phillips Laboratory awarded contracts worth $4 million each to Lockheed Martin and McDonnell Douglas Space Division to develop concept designs for a sub-orbital demonstrator. Lockheed Martin has offered a concept based on its X-33 design, while McDonnell Douglas has proposed a concept based on the Clipper Graham.[70]

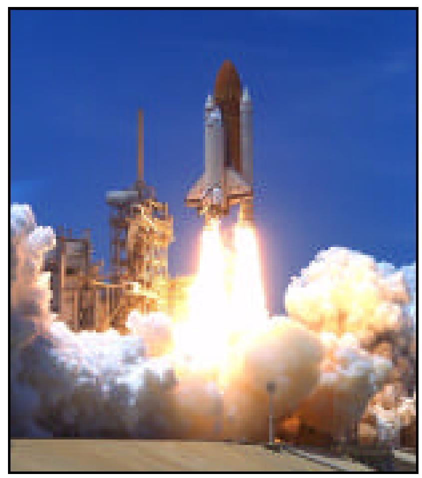
The SMV is under development by Boeing North American, and an 85% scale unpowered testbed has been produced under a $5.2 million contract awarded in October 1996 by the USAF's

Wright Laboratory.[71] The testbed will be carried aloft by helicopter, where it will be released to demonstrate automated landing procedures. Three landing tests were planned for the fall of 1997, but the current program status is uncertain due to funding questions. With funding, further landing tests and ground procedure testing could proceed in 1998.[72]

The full-scale powered SMV will be designed to be about 7.5 meters long and have a mass of about 1140 kg. The Air Force is also considering future designs of the SMV to include crewed versions. Should the USAF proceed with development of the SMV, testing could proceed with unpowered drops from a B-52, followed by missions into space for return-from-orbit tests.[73]

The availability of funds for the military spaceplane is in doubt because of President Clinton's October 1997 line-item veto of the program's funding. The Air Force has stated publicly that funding could continue in 1999 should the veto not be overturned.[74] A senior Air Force official at the Phillips Laboratory, however, stated that funds that were supposed to be earmarked for the program had not been allocated to the program, and that the continuation of the program without the funds vetoed by the president is unlikely.[75]

Space Shuttle



The United States' Space Shuttle fleet was first launched in 1981 and since then has provided the basis for NASA's crewed missions to space. Although the Space Shuttles have launched several commercial and military satellite payloads during their initial years of service, commercial payloads have been effectively banned from the shuttles since the explosion of the *Challenger* orbiter in 1986. The transition of Space Shuttle program operations management from NASA to a private organization, however, has raised the possibility that the shuttle fleet could engage in a range of commercial operations in the future.

Vehicle: Space Shuttle

Developer: Rockwell International, Lockheed Martin, Thiokol. Operated by United Space Alliance (USA)

First launch: 1981

Number of stages: 2 (3 with upper stage for GEO launches)

Possible launch sites: CCAS

Markets served: Science missions. Launch of heavy-class LEO satellites. Satellite repair missions. Delivery of supplies to the International Space Station. Orbital space tourism.

Funding: USA has a $7 billion contract with NASA

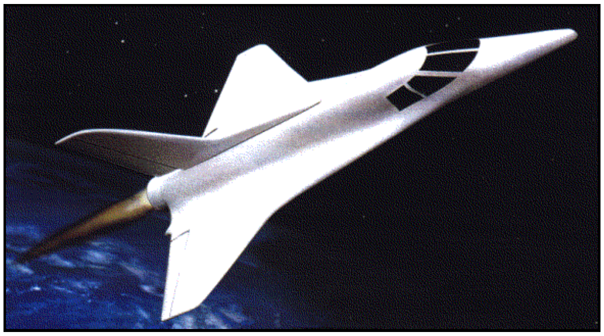
The Space Shuttle fleet consists of four orbiters (*Columbia*, *Discovery*, *Atlantis*, *Endeavor*) that measure 37.2 meters in length and have dry masses ranging from 78,400 kg to 82,200 kg. Each orbiter is mated to an external fuel tank and two solid rocket boosters for vertical launches. The solid rocket boosters supplement the thrust of the three LOX/liquid hydrogen engines of the orbiter. The orbiter can carry a crew of 7 and a payload of up to 24,400 kg to LEO. After completing operations in orbit, the orbiter re-enters the atmosphere and lands horizontally.[76]

In October 1996, United Space Alliance (USA), a joint venture of Lockheed Martin and Boeing, took over day-to-day operations of the Space Shuttle fleet under a six-year contract with NASA. USA has offered a plan to NASA under which the shuttle fleet could begin carrying commercial payloads within a year and which calls for the privatization of the fleet by 2002. USA believes that the shuttle fleet can provide services such as launches for governments and commercial entities, satellite retrieval or repair, International Space Station delivery in the near term. In the future, the shuttle fleet could also serve emerging markets such as space-based biomedicine and space tourism. [77]

In order to provide commercial services, however, the cost of launching payloads must be reduced. Such cuts in cost could come from increasing the flight rate (from the current 7 per year to 15 per year or more) or from modifications and improvements to the vehicles. One modification currently under study is a change from the current solid rocket boosters, which must be recovered at sea, to liquid-propelled boosters that are capable of flying back to the launch site under their own power. [78] Liquid fly-back boosters are currently under study at NASA's Marshall Space Flight Center.

International Concepts

International public and private organizations are also designing RLVs to satisfy government and commercial launch needs. As with the US commercial vehicles in the previous section, these vehicles are in various stages of development. Several of these concepts, such as the SKYLON, the Spacecab/Spacebus, and the Sänger spaceplane, have been under development since the 1980s. Others, like the Kankoh-Maru, are only under study.



Vehicle: Ascender

Developer: Bristol Spaceplanes Limited

First launch: TBA

Number of stages: 1

Possible launch sites: TBA

Markets served: Suborbital space tourism. Sounding missions.

Funding: Program funding is not known.

Bristol Spaceplanes Ltd. – Ascender [79]

The Ascender is a proposed passenger-carrying spaceplane designed by Bristol Spaceplanes Limited of Great Britain. Bristol Spaceplanes Limited (BSL) was formed in 1991, and its director, David Ashford, has long been involved in space tourism and RLV concepts.[80] Ashford has written publications detailing plans for TSTO RLVs and advocating space tourism opportunities.

The 7.9-meter long Ascender is designed to carry two passengers and a crew of two to a sub-orbital altitude of 100 km for space tourism flights, potentially making several flights per day. Alternatively, the Ascender can act as a reusable sounding rocket (a potential market that Kelly Space and Technology's Sprint vehicle may pursue). The Ascender is also planned to be the forerunner of larger-scale commercial RLVs, the Spacecab and Spacebus (see the Spacecab/Spacebus entry on page 38).

BSL is currently seeking private funding for the Ascender. BSL has registered as a competitor for the X PRIZE℠ and is designing the Ascender as its entry.

NASDA – HOPE-X Spaceplane

Vehicle: HOPE-X
Developer: NASDA
First launch: 2001
Number of stages: 3
Possible launch sites: Tanegashima
Markets served: Delivery of supplies to International Space Station.

Funding: Program is funded for $1.2 billion by the Japanese government.

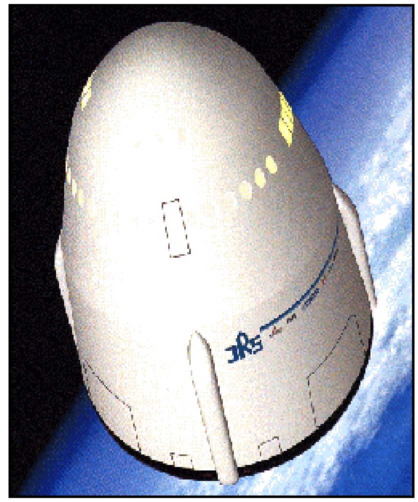
The Japanese space program began studying the development of a small crewless space shuttle in 1987. The original parameters called for a 20,000 kg vehicle that would be lifted by the H-2 booster and would land by remote control in Japan or Australia.

To this end, the Japanese space agency (NASDA) initiated the H-2 Orbiting Plane (HOPE) program. NASDA has moved the program gradually through a series of development steps over the last ten years. The program progressed though two major testbeds, the HYFLEX (Hypersonic Flight Experiment), which consisted of a lifting body aircraft used to study hypersonic flight following launch from rocket booster, and the ALFLEX (Automatic Landing Flight Experiment), which consisted of a one-third model of the HOPE spaceplane and performed automated landing tests.[81]

The program had called for a HOPE-X prototype to be built and tested before a full-scale version was produced. A funding decision made in the summer of 1997 by the Japanese government, however, changed the scope of the HOPE project significantly. In order to save money and cut down on the number of steps to reach a long term goal of a fully-reusable SSTO spaceplane (see SSTO spaceplane entry on page 36), the government decided to eliminate the final full-scale HOPE vehicle and modify the HOPE-X prototype to provide regular operations. The HOPE-X vehicle will measure about 16 meters long and will receive improved ceramic thermal protection, a cargo bay, and an in-orbit maneuvering engine. The HOPE-X will also be launched from the new, less expensive H-2A vehicle.[82]

With the new development plan in place, the Japanese expect that the modifications to the HOPE-X spaceplane should allow it to launch in 2001.

Japanese Rocket Society – Kankoh-Maru [83]



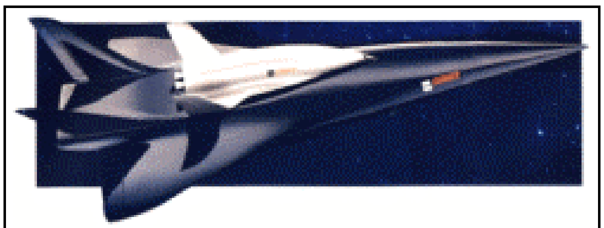
Kankoh-Maru is a passenger carrying RLV concept under study by the Japanese Rocket Society. In 1993, the Japanese Rocket Society began a Space Tourism Study Program to study methods of making launch services and space flight available to the general public. The concept design for the Kankoh-Maru has been introduced and refined since that time.

The Kankoh-Maru design is based on space tourism applications. The vehicle concept under study is a SSTO rocket that would offer areas to sit and areas for passengers to move around in weightlessness and would be capable of carrying 50 passengers to a 200 km orbit.

The Kankoh-Maru remains a study concept of the Japanese Rocket Society, and no funding has been announced for the design of this vehicle.

Vehicle: Kankoh-Maru
Developer: Japanese Rocket Society
First launch: TBA
Number of stages: 1
Possible launch sites: TBA
Markets served: Orbital space tourism.
Funding: Program is not funded.

Daimler Benz Aerospace – Sänger



Vehicle: Sänger
Developer: Daimler-Benz Aerospace AG
First launch: TBA
Number of stages: 2
Possible launch sites: TBA
Markets served: Launch of medium-class LEO payloads. Orbital space tourism.
Funding: First phase of the program is complete. Second phase of the program is not funded.

The Sänger spaceplane concept was developed in Germany in the 1970s, but the vehicle remained a concept without a program until the 1980s. In 1986, the ESA began examining designs for a follow-on vehicle to the proposed Hermes spaceplane. Germany proposed the Sänger design, and British Aerospace Space Systems (now Matra Marconi) offered the Horizontal Takeoff and Landing (HOTOL) spaceplane, which would consist of a reusable spaceplane carried aloft by a conventional transport aircraft and landing horizontally. In 1990, British Aerospace and the Soviet Ministry of Aviation Industry agreed to develop an interim HOTOL design that would use an An-225 transport as the carrier aircraft. ESA funded this effort through the Rocket-ascent demonstrator (Radem) study, but ESA funding and HOTOL development ceased with the end of this program.[84]

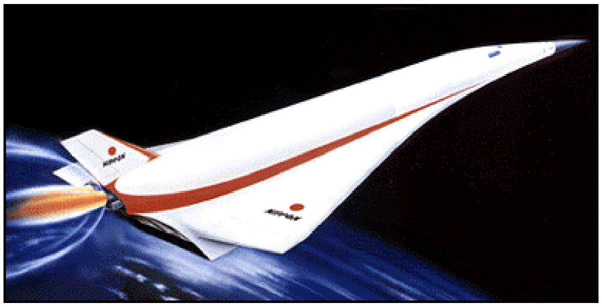
While HOTOL was ESA's initial choice for further development, the German government lobbied for Sänger as an alternative. Though Sänger was rejected by ESA, Germany initiated a National Hypersonics Technology program in 1988 to study the propulsion and structural systems that Sänger would require. With this first phase of development complete, a second phase of the program would produce the Hytex demonstrator vehicle. The second phase of the program was originally planned to begin in 1993, but funding problems have stalled the program.[85]

Sänger is designed as a two-stage-to-orbit spaceplane consisting of a hypersonic boost stage known as the European Hypersonic Transport Vehicle (EHTV) and a reusable rocket-powered orbiter known as Horus (Hypersonic Reusable Orbital Upper Stage). Takeoff and landing for both stages is horizontal. The EHTV would be powered by six airbreathing turbo-ramjets which use liquid hydrogen as propellant for hypersonic flight and which function as kerosene powered turbofans for subsonic flight. EHTV would measure about 82 meters in length and have a dry mass of about 177,000 kg.[86] EHTV would accelerate to Mach 6, at which time Horus would separate and climb to orbit.[87] Horus would use an Advanced Topping Cycle Rocket Engine for propulsion. Horus would be about 32 meters long, with a dry mass of about 35,000 kg. Horus designs for carrying 36-44 passengers have been developed,[88] and variants of Horus to carry crew and cargo are also under study.

Daimler-Benz Aerospace AG (DASA) is the prime contractor for Sänger, and other European space industry firms such as Alenia SpA, Saab Ericsson Space, and MAN Technologie GmbH have also participated in Phase 1.

The Teal group estimates that the Sänger program will cost $20 billion. The Sänger program has recently received a boost as the ESA has chosen Sänger for the Future European Space Transportation Investigation Program (FESTIP). The availability of ESA funding for the FESTIP program, however, remains in doubt. ESA will wait until 2005 to decide whether to proceed with full scale development of the vehicle.

National Aerospace Laboratory (Japan) – SSTO Spaceplane



Vehicle: SSTO Spaceplane

Developer: National Aerospace Laboratory (Japan)

First launch: 2010

Number of stages: 1

Possible launch sites: TBA

Markets served: Launch and recovery of heavy-class LEO payloads.

Funding: Program funded to an unknown level by the Japanese government.

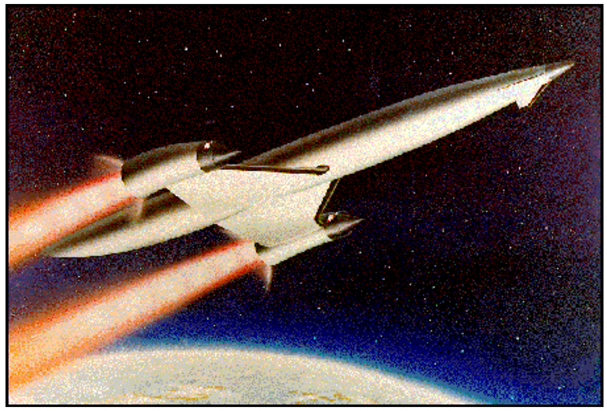
Japan's long-term reusable launch vehicle goal is the construction of a SSTO spaceplane. The Japanese government cut funding for the HOPE spaceplane (see HOPE-X entry on page 33) in order to reduce the number of intermediate steps to reach the goal of a fully reusable SSTO vehicle in the long run. Following the recommendation of the Committee on Future Fully Reusable Space Transportation Systems, the design for a SSTO RLV is being explored and refined by the National Aerospace Laboratory.

The National Aerospace Laboratory concept calls for the development of a SSTO prototype rocket by 2010 and a final SSTO spaceplane by 2020.[89] The companies of the Space Plane Committee of the Society of Japanese Aerospace Companies (Mitsubishi, Ishikawa-jima-Harima, Kawasaki, Fuji, and Sumitomo) have all been developing advanced propulsion systems in support of the program. Development of the spaceplane is expected to cost $20 billion.[90] These concepts are still in the early development stages, but they represent the official direction for Japan's RLV development.

The SSTO Spaceplane would take off and land horizontally and carry a crew of four. The vehicle would measure about 65 meters in length, with a dry mass of about 101,000 kg.

The final SSTO Spaceplane would utilize either air-breathing propulsion for atmospheric flight and multiple rocket engines to achieve orbit or may employ new hybrid engines. Propulsion concepts favored for the spaceplane include liquefied air cycle engines (LACE) and scramjets. LACE engines liquefy air at low altitudes and accumulate oxygen to be used later at higher altitudes. In one design concept, LACE would be used to power the craft to Mach 5 and 20 km altitude, where scramjets would be activated to accelerate the vehicle to Mach 20. The LACE engines would then switch to rocket mode to achieve orbit. Engines that combine the aspects of both LACE and scramjets (known as combined cycle engines) may be developed to provide an optimal combination of weight and power.[91]

Reaction Engines Ltd. – SKYLON

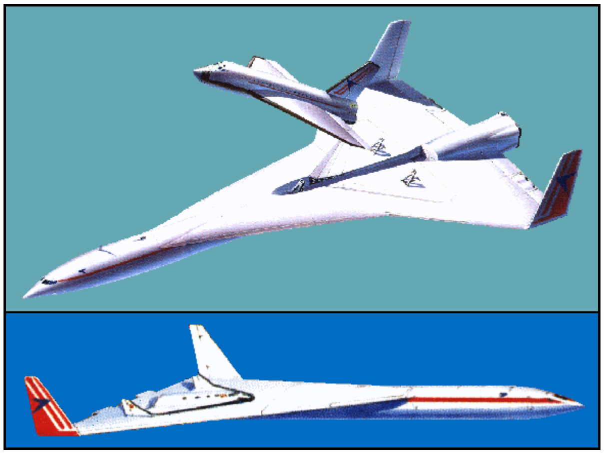


The SKYLON spaceplane was proposed in 1993 by Alan Bond of Great Britain. Bond designed the dual-mode propulsion system (engines that operate using air for atmospheric flight and LOX or other liquid propellants to reach orbit) for the defunct HOTOL spaceplane concept (see Sänger entry on page 34). Bond and his company Reaction Engines Ltd. had hoped to introduce SKYLON to the ESA as the design for the FESTIP program (see Sänger), but were unable to get funding from the British government to make the proposal.[92]

Vehicle: SKYLON
Developer: Reaction Engines Ltd.
First launch: 2010
Number of stages: 1
Possible launch sites: TBA
Markets served: Sale of vehicles for launch of heavy-class LEO payloads and orbital space tourism.
Funding: Program is not funded.

SKYLON is an SSTO spaceplane designed for horizontal takeoff and landing. The vehicle measures about 82 meters long and has a dry mass of about 55,000 kg.[93] SKYLON would be powered by two "synergetic air-breathing and rocket engines" (SABREs). A SABRE integrates a turbo-ramjet and a rocket motor using LOX and liquid hydrogen into a single engine. SKYLON would be capable of placing heavy payloads into LEO (about 10 metric tons to 400 km) and could also perform space tourism and fast passenger service missions.[94]

Prospects for the further development of SKYLON are uncertain. Bond will need to seek either government funding or commercial investors to be able to continue the SKYLON. Reaction Engines has sought to form an international consortium of interested firms in order to raise funds for the development of SKYLON but to date has not achieved this goal. Reaction Engines claims that there is potential demand for as many as 40 such vehicles, and that a 10,000 kg payload would cost about $6 million to launch to LEO. Reaction Engines plans to sell SKYLON vehicles to providers of launch and space tourism services, rather than providing such services on its own.



Vehicle: Spacecab (above)/Spacebus (above-top)
Developer: Bristol Spaceplanes Ltd.
First launch: 2010
Number of stages: 2
Possible launch sites: TBA
Markets served: Orbital space tourism. Launch of small-class LEO payloads. ISS crew transfer. Repair of LEO satellites.
Funding: Program is not funded.

Bristol Spaceplanes Ltd. – Spacecab/Spacebus

Spacecab and Spacebus are similar concepts promoted by Bristol Spaceplanes Limited (BSL). BSL is headed by David Ashford, an advocate of space tourism for many years, and has entered its Ascender vehicle in the X PRIZE[SM] competition (see Ascender entry on page 32 for more information).

The Spacecab would be a prototype two-stage spaceplane. The first stage would consist of a supersonic aircraft similar to the Concorde but equipped with four air-breathing and two rocket engines, allowing acceleration to Mach 4. Upon reaching Mach 4, the second stage reusable orbiter would separate from the top of the first stage and use rocket power to reach orbit. The orbiter would be similar in size and design to the Ascender vehicle but would be capable of carrying two crew with either six passengers or 750 kg of cargo. Both the booster and the orbiter would land horizontally.[95]

Spacebus is an enlarged version of the Spacecab. The Spacebus booster would have a length of approximately 88 meters and a mass of 130,000 kg, while the orbiter would be 34 meters long with a mass of 19,900 kg. The Spacebus booster would have greater power and accelerate to Mach 6 for orbiter separation. The orbiter would be capable of carrying 50 passengers.[96]

According to BSL, Spacecab can be built using existing technology, and the development cost and timetable of the prototype of each stage should be comparable with that of the prototype of an advanced aircraft. The prototype could be used for early operational flights to and from orbit and could launch small satellites and ferry crews and passengers to and from space. BSL completed a feasibility study of the Spacecab and Spacecab demonstrator vehicles for ESA in 1994, but ESA has not acted to develop the concept any further.[97]

X PRIZE℠ Competitors

The commercial vehicles under development for the X PRIZE℠ competition are generally uniquely designed for sub-orbital space tourism operations carrying about 3-6 passengers. These designs use many different takeoff, landing, and propulsion concepts, but all plan to use existing technology to accomplish their goals. The X PRIZE℠ competition criteria requires vehicles be capable of carrying 3 people to a 100 km suborbital altitude and repeating the flight within two weeks.

Advent Launch Services – CAC-1

The CAC-1 is the X PRIZE℠ entry of Advent Launch Services. Advent is partnered with an organization known as the Civilian Astronaut Corps (CAC). The CAC plans to contract with Advent Launch Services to build the CAC-1 and is selling memberships in their organization in order to raise funds. Members will ride into space when the CAC-1 becomes operational.[98]

The CAC-1 is planned as a SSTO rocket powered by 8 engines of the type used on the Apollo moon lander. The CAC-1 employs a water launch method in which the vehicle is taken out to sea by ship or barge and tethered to the sea floor for a vertical launch. The vehicle will climb to approximately 110 km following engine shut-down. Upon re-entering the atmosphere, the vehicle will pull into a supersonic glide at an altitude of about 9 km (30,000 ft.) and then decelerate and land horizontally in the water.[99]

Advent Launch Services was founded in 1995 and is still seeking funding to proceed with development of the CAC-1. Advent believes that the CAC-1 can serve the space tourism market and also provide passenger service to port cities around the globe.[100]

Vehicle: CAC-1

Developer: Advent Launch Services

First launch: 1999

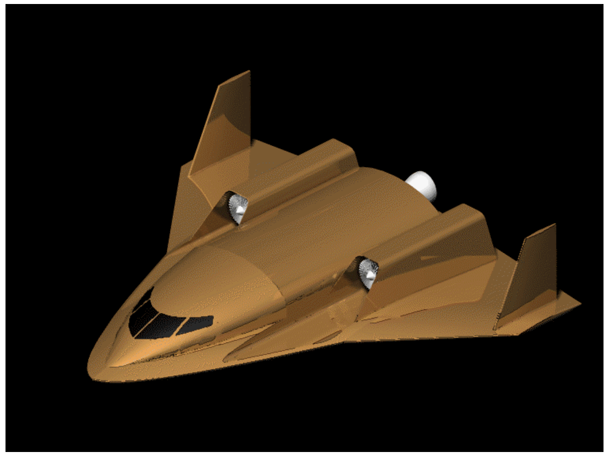
Number of stages: 1

Possible launch sites: Gulf of Mexico off Galveston, TX

Markets served: Suborbital space tourism. Worldwide passenger service.

Funding: Program funding is unknown.

Dynamica Research – Cosmos Mariner [101]



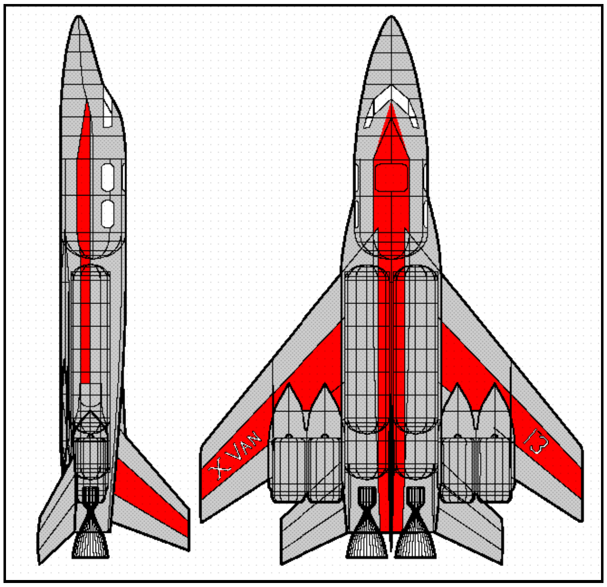
The Cosmos Mariner is the X PRIZE℠ entry of Dynamica Research, a Texas-based aerospace firm. Dr. Norman LaFave is president and CEO of Dynamica Research. Dr. LaFave and his staff have many years of experience in aerospace engineering with NASA, the FAA, the military, and private industry.

Vehicle: Cosmos Mariner	
Developer: Dynamica Research	
First launch: TBA	
Number of stages: 1 (2 for payload launches)	
Possible launch sites: Ellington Field (Houston)	
Markets served: Suborbital space tourism. Launch of LEO satellites using small piggyback payload upper stage. Fast package delivery. Fast passenger service.	
Funding: Program funding is unknown.	

The Cosmos Mariner measures approximately 27 meters in length. The vehicle is designed to use two conventional air-breathing engines and one rocket engine. The rocket engine will use LOX and conventional jet fuel as propellants. The vehicle will be capable of carrying 4 passengers without modification. The vehicle will also be capable of carrying a 11,000 kg payload consisting of an additional passenger module or a booster rocket that could carry a 900 kg payload to LEO. Dynamica plans to use available technologies to reduce costs and development time.

Dynamica Research has designed the Cosmos Mariner to operate from conventional airports and use the air traffic control system while operating in the atmosphere under jet power.

Dynamica Research believes that it could possibly serve small payload launch, worldwide package delivery, space tourism, high-speed travel, and sounding payload markets with this vehicle.



Third Millennium Aerospace – X Van [102]

The X Van is the X PRIZE℠ entry of PanAero, Inc. and Third Millennium Aerospace. The X Van would measure about 12 meters long and would be capable of carrying three passengers to 100 km.

Third Millennium Aerospace hopes to use the X Van as the jumping off point for the commercial applications of its Bantam Van and Space Van (see Space Van/Bantam Van entry on page 17). The developers have also indicated that a scaled-up version of the X Van vehicle could be used as the booster segment of the Space Van/Bantam Van vehicles.[103] More information on Third Millennium's business plans are found in the Space Van/Bantam Van entry on page 17.

Vehicle: X Van

Developer: Pan Aero, Inc., Third Millennium Aerospace

First launch: TBA

Number of stages: 1

Possible launch sites: TBA

Markets served: Suborbital space tourism.

Funding: Program funding is not known.

The X Van would launch vertically using four air-breathing engines. After climbing to altitude, two rocket motors (defined by Third Millennium as "pressure-fed propulsion modules") are started to carry the vehicle to 100 km. Upon reentry, the air-breathing engines are restarted and the vehicle returns to a vertical hover before landing. The landing is accomplished by maneuvering the vehicle in the vertical position onto a crane or gantry device. The vehicle will then latch on to the gantry using a hook. Experimental tests for this landing concept were conducted by the X-13 aircraft in 1955.

PanAero has obtained a permit for permanent import into the United States of the Rybinsk RD-38 lift jet engines. PanAero is currently negotiating with Rybinskie Motory joint stock company in Rybinsk, Russia for use of their RD-38 engines for the X Van, the Bantam Van, and other applications. PanAero plans to join in a coordinated group with three other American companies for the development of the pressure-fed rocket propulsion modules.

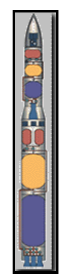
Other X PRIZE^{SM} Competitors

Several other companies and individuals have registered as competitors for the X PRIZE^{SM}, but not all of them have made information about their designs available to the public. The remaining X PRIZE^{SM} competitors, and information about their vehicles where available, are listed below:

Burt Rutan – Proteus

Burt Rutan and his team from Scaled Composites are designing the Proteus TSTO launch vehicle for the X PRIZE^{SM}. The concept consists of a boost stage (the "Mothership") configured as a conventional turbofan-powered aircraft. This stage carries a smaller, rocket-powered second stage that carries the passengers. After climbing to 37,000 feet, the Mothership pitches up and releases the second stage. The second stage accelerates under power to 100 km and continues to coast on a suborbital trajectory. Mr. Rutan has not disclosed the powerplants for the vehicles or the landing method for the vehicle stages.

Rick Fleeter – PA-X2

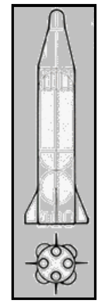


Rick Fleeter and AeroAstro have entered the PA-X2 design for the X PRIZE^{SM}. This vehicle appears to be a modification of the PA series of expendable launch vehicles that the PacAstro division of AeroAstro is currently designing. The PA-X2 will use a LOX/kerosene pressure-fed engine and will be launched vertically from a simple pad and launch rail. Upon reentry, the vehicle deploys a steerable parafoil and lands horizontally with airbags for cushioning.

Pablo De Leon and Associates – Gauchito

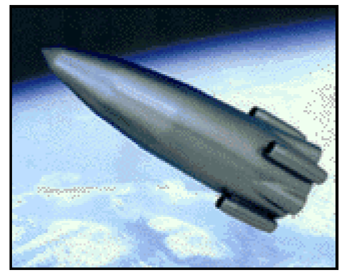
Pablo De Leon and Associates are designing a vertical takeoff TSTO vehicle for the X PRIZE^{SM}. This vehicle will consist of a reusable booster and a reusable passenger capsule. Both the booster and the capsule will be recovered following parachute landings. The vehicle will use four hybrid engines (Mr. De Leon does not define hybrid) that will burn from lift-off until an altitude of 34 km. The vehicle then coasts to a 120 km altitude. Following about five minutes of weightlessness, the pilot orients the capsule for descent. Parachutes slow the capsule following its return to the atmosphere.

Graham Dorrignton – Green Arrow



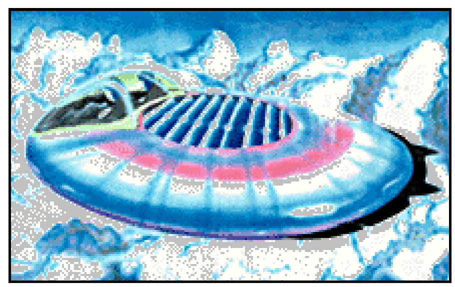
Dr. Graham Dorrington's X PRIZE[SM] entry is named the Green Arrow after an old British rocket design. This SSTO vehicle will use LOX and hydrogen peroxide as propellants. The Green Arrow will launch vertically and climb to an altitude of about 100 km. The vehicle lands vertically using parachutes to slow descent and air bags for cushioning.

Steven Bennett – Thunderbird



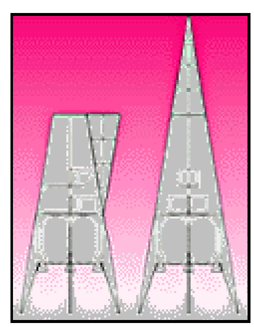
Steven M. Bennett and the Starchaser Foundation have entered the X PRIZE[SM] competition with this SSTO design. The Thunderbird takes off using turbofan engines and then switches to LOX/kerosene engines in the upper atmosphere. After coasting to 100 km, the vehicle will reenter the atmosphere and land vertically.

John Bloomer – The Space Tourist



John Bloomer, founder of the Discraft Corporation has introduced "The Space Tourist" entry for the X PRIZE[SM]. This vehicle is being designed to take off and land horizontally from conventional runways. Propulsion will be provided by what Mr. Bloomer calls blastwave pulsejets. This saucer-shaped vehicle also features a large, laminar-flow wing. The vehicle will accelerate using the air-breathing engines on a gradually ascending arc and will exit the atmosphere at Mach 10 and coast to a 75 mi. altitude. The vehicle will return to earth on a gradually descending arc.

Mickey Badgero – Lucky Seven



Mr. Badgero is on active duty in the USAF and is designing the Lucky Seven to compete for the X PRIZE[SM]. The SSTO Lucky Seven will be powered by as-yet unspecified rocket engines and will launch vertically. Following a 1.5-minute main engine burn, the vehicle will coast to above 100 km. After reentry, the Lucky Seven will use a parafoil to glide to its landing area.

Others

Paul and Helen Tyron plan to enter the X PRIZE^{SM} competition with a rocket-powered version of a military aircraft. They plan to modify an F-4, F-18, or F-5 aircraft (with the F-4 preferred). The vehicle will accelerate under rocket power to 100 km and then glide unpowered back to the landing site. Takeoff and landing will be horizontal from conventional runways.

Mr. William Good is the president of the Earth Space Transport Corporation and has not released details of his design.

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Reusable Launch Vehicle Programs and Concepts Table

Vehicle	First launch	Manufacturer/ Developer	Number of stages	Powerplants	Performance	Launch method	Recovery method	Launch Contracts	Government funding	Potential Markets Served	Subcontractors	Commercial Investors	Possible launch sites
NASA RLV Program													
Clipper Graham Clipper Graham-XA (DC-XA)	1993	Boeing (McDonnell Douglas Space Division)	1	CG-XA demonstrator: Four Pratt and Whitney RL10A-5 LOX/hydrogen engines Full scale Clipper Graham: TBA	CG-XA demonstrator: testing to 3.1 km altitude Full scale Clipper Graham: 10,000 kg to LEO 8200 kg to space station orbit 4500 kg to 740 km Polar	vertical launch	vertical landing	no	yes	Demonstration of VTOL capabilities, RLV materials, and rapid turn-around operations.	Pratt and Whitney, AlliedSignal, Chicago Bridge and Iron Services, General Connector, Harris, Integrated Systems, Lockheed Martin, New Mexico State University, Process Fabrication Inc., Space Guild		White Sands Missile Range
X-33/ Venturestar	2001	Lockheed Martin Skunk Works	1	2 J-2S linear aerospike engines (X-33) 7 RS-2200 linear aerospike engines (Venturestar)	18,000 kg to LEO	vertical launch	horizontal landing	no	yes	Testbed for RLV technologies and operations. Venturestar launch of heavy-class LEO payloads.	LM Space Operations, LM Manned Space Systems, LM Astronautics, LM Engineering and Sciences, Sanders, Rocketdyne, Rohr, AlliedSignal, Alliant Techsystems, Sverdrup		
X-34	1998	Orbital Sciences Corporation	1	One kerosene/LOX Fastrac engine	Mach 8 at 250,000 ft.	air-launched	horizontal landing	no	yes	Sub-orbital demonstration of RLV technology.	AlliedSignal, Oceaneering Incorporated, Draper Laboratories		White Sands Missile Range
Future X Trailblazer program	TBA	TBA	TBA	Advanced LOX/RP Propulsion Integration of airbreathing engines	Orbital or Earth orbital transfer capability	TBA	TBA	no	yes	Demonstration of integrated technology concept vehicles.			
Future X Pathfinder program	TBA	TBA	TBA	Solar electric propulsion Rocket-based combined-cycle engines	Hypersonic sub-orbital or orbital capability	TBA	TBA	no	yes	Demonstration of specific technology advancements.			
NASA X-38 Program													
X-38/Crew Return Vehicle	1999	Scaled Composites	TBA	X-38: none CRV: Expendable Deorbit Propulsion Stage (DPS)	6 crew from Space Station to Earth	on-board Space Shuttle	horizontal landing	no	yes	Prototype for International Space Station crew return operations	Pioneer Aerospcace, SSE Inc.		CCAS
US Military Programs													
Military Spaceplane	TBA	Boeing North American, Lockheed Martin, McDonnell Douglas Space Division	2	Hypersonic first stage: similar design to X-33 or Clipper Graham Space Maneuver Vehicle (SMV) second stage: TBA	450 kg to LEO	vertical launch	horizontal or vertical landing	no	yes	Military payload delivery or special missions such as satellite orbital transfer or satellite neutralization.			
Commercial Launch Programs													
Advent heavy lift LV	TBA	Advent Launch Services	2	Multiple Lunar Descent Engines	9000 kg to LEO	vertical water launch	horizontal water landing	no	no	Launch of heavy-class LEO payloads.			Gulf of Mexico
Astroliner E-100	2001	Kelly Space and Technology	3	Engines under consideration include: GenCorp Aerojet's NK-33, Rockwell Rocketdyne Division's Aerospike and RS-27, or NPO's RD-180; Launches of Iridium satellite pairs may use Thiokol Star 48B for the second stage and Star 63F for the third stage	1591 kg to 463 km Polar 1733 kg to 185 km Polar 1931 kg to 463 km 28.5 deg. LEO 9000 kg sub-orbital payload capacity	air-launched	horizontal landing	yes	no	Launch of LEO constellation satellites.	ACTA, Aircraft Technical Services, GenCorp Aerojet, AeroLaunch Systems Corporation, Altair, Frontier Engineering, Menasco, Modern Technologies Corp., Oceaneering Space Systems, Pioneer Aerospace, Thiokol, Tracor, TRW, Universal Space Lines	Motorola has signed $89 million contract with KST for ten launches of twenty Iridium satellites	Atlantic City NJ, Vandenberg AFB, White Sands Missile Range
Express	1998	Kelly Space and Technology	2	Engines under consideration in 1996 included: TRW Pintle engine, Fastrac engine, Aerojet NK-31 liquid engine; Will use a conventional expendable upper stage like the Astroliner	23 kg to 463 km Polar 32 kg to 185 km Polar 45 kg to 463 km 28.5 deg. LEO 450 kg sub-orbital payload capacity	air-launched	horizontal landing	no	yes	Launch of suborbital payloads or LEO microsatellites.	as above		as above
Sprint	1998	Kelly Space and Technology	2	Air breathing jet engine or LOX/kerosene rocket engine Vehicle may eventually carry an expendable upper stage for sounding missions	273 kg sub-orbital payload capacity	air-launched	horizontal landing	no	yes	Launch of sounding rockets for microgravity and other missions.	as above	Mainly financed by individual investors with moderate contributions	as above
Astroliner E-250	TBA	Kelly Space and Technology	3	Engine for spaceplane is not specified liquid upper stage	Goal of 4100 kg to GTO	air-launched	horizontal landing	no	no	Launch of medium-class GTO payloads.			
K-1	1998	Kistler Aerospace Corporation	2	First stage: 3 NK-33 kerosene/ LOX engines Second stage: 1 NK-43 kerosene/ LOX engine	4900 kg to 200 km 52 deg. LEO 2275 kg to 750 km 52 deg. LEO 2950 kg to 200 km 28 deg. LEO 990 kg to 639 km Polar	vertical launch	parachutes and air bags (both stages)	yes	no	Launch of LEO constellation satellites.	GenCorp Aerojet, Northrop Grumman, Lockheed Martin, Draper Laboratories, AlliedSignal, Irvin Aerospace, Honeywell, Motorola, Rami, MPI	Space Systems/Loral has signed $100 million contract with Kistler Aerospace for ten launches	Woomera, Australia; DOE Nevada Test Site
Pathfinder	TBA	Pioneer Rocketplane	2	2 Pratt and Whitney F100 air-breathing engines, 1 RD-120 LOX/kerosene engine	2500 kg to LEO with STAR 75 upper stage 1000 kg to LEO with STAR 48B upper stage	horizontal take-off	horizontal landing	no	yes	Launch of medium-class LEO payloads. Sounding missions (short-duration space research). Vehicle sales for fast passenger service, fast package delivery, and military missions.			Wallops Island, Vandenberg, Kodiak Island
Roton-C	1999	Rotary Rocket Company	1	Rocketjet aerospike LOX/ jet fuel engine	3175 kg to LEO	vertical launch	vertical landing	no	no	Launch of LEO constellation satellites. Vehicle sales for space tourism, fast passenger service, and fast package delivery.	Scaled Composites, Ray Prouty, Advanced Rotorcraft Technologies, Deskin Research Corp., Hypersonics Inc., Aerotherm Corp., Altus Associates, Luna Corp.		
Space Cruiser System (SCS)	2001	Vela Technology Development, Inc. Zegrahm Space Voyages	2	Lower stage: 2 JT8D/F100-class turbo-jet engines Upper stage: 3 Nitrous Oxide/Propane, pressure fed, rocket engines, two JT15D-class turbo-jet engines	6 passengers and 2 crew to 100 km suborbital	horizontal take-off	horizontal landing	yes	no	Suborbital space tourism. Suborbital microgravity and other experiments. Aerospace training.	AeroAstro		Commercial airports capable of servicing business jets
Space Shuttle	1981	Rockwell, Rocketdyne, Lockheed Martin	2	3 Rocketdyne LOX/hydrogen Space Shuttle Main Engines	24,950 kg to 204 km 28 deg. LEO 18,600 kg to 204 km 57 deg. LEO 13,426 kg to 204 km 98 deg. sun-synchronous	vertical launch	horizontal landing	yes	yes				
Space Van/ Bantam Van	TBA	Third Millennium Aerospace	2	Space Van: One RD-120, Two Pratt & Whitney RL10A-4-1 Bantam Van: One RL10A-4-1	Space Van: 4200 kg to 40 deg. LEO Bantam Van: 400 kg to 450 km, 40 deg. LEO or 4-16 passengers	horizontal take-off	horizontal landing	no	no	Orbital space tourism. Launch of GEO payloads. Launch of LEO constellation satellites. Mining of He_3 from the moon.			
International Concepts													
Ascender (Great Britain)	TBA	Bristol Spaceplanes Limited	1	2 Williams Rolls FJ441, one Pratt & Whitney RL10	4 passengers to 50 mi.	horizontal take-off	horizontal landing	no	no	Suborbital space tourism.			
HOPE-X Spaceplane (Japan)	2001	NASDA	3	Thrusters utilizing nitrogen tetroxide and either monomethelhydrazine or hydrazine	3000 kg to space station orbit	vertical launch with H-2A booster	horizontal landing	no	yes	Delivery of supplies to International Space Station (ISS).	Fuji Heavy Industries, Kawasaki Heavy Industries, Mitsubishi Corp.		Tanegashima
Kankoh-Maru (Japan)	TBA	Japanese Rocket Society	1	Multiple liquid Oxygen/liquid Hydrogen engines	50 passengers to 200 km LEO	vertical launch	vertical landing	no	no	Orbital space tourism. Launch of small-class LEO payloads. ISS crew transfer. Repair of LEO satellites.			
Sänger (Germany-ESA)	TBA	Daimler-Benz Aerospace AG	2	First stage: six airbreathing liquid hydrogen ramjets Second stage: Advanced Topping Cycle Rocket engine	7000 kg to 465 km 28.5 deg. LEO 3300 kg to 465 km 28.5 deg. LEO with 5 crew	horizontal take-off	horizontal landing	no	yes	Launch of medium-class LEO payloads.	Alenia SpA, Linde AG, Man Technologie GmbH, Raufoss A/S, Sabb Ericsson Space AB, Volvo Flygmotot AB		
SSTO Spaceplane (Japan)	2010	National Aerospace Laboratory	1	Multiple liquid propellant engines Airbreathing engines for atmospheric flight	10000 kg to 500 km 28.5 deg. LEO	horizontal take-off	horizontal landing	no	yes	Launch and recovery of LEO payloads.			
Skylon (Great Britain)	2005	Reaction Engines Ltd.	1	2 SABRE hybrid air-breathing and LOX/LH rocket engines	12 tons to 300 km equatorial 10.5 tons to 400 km LEO 9.5 tons to 460 km 28.5 deg. LEO or 60 passengers	horizontal take-off	horizontal landing	no	no	Vehicle sales for launch of heavy-class LEO payloads, orbital transfer operations, and orbital space tourism.			
Spacecab/ Spacebus (Great Britain)	TBA	Bristol Spaceplanes Limited	2	Lower stage: combination of air-breathing and rocket engines Upper stage: six RL-10 or HM7 class engines	Spacecab: 6 passengers/space station crew 1000 kg to LEO	horizontal take-off	horizontal landing	no	no	Orbital space tourism. Launch of small-class LEO payloads. ISS crew transfer. Repair of satellites in LEO.			
Spacecub	TBA	David L. Burkhead	1	4 Oxygen/ Kerosene engines	4 passengers	vertical launch	vertical landing	no	no	Suborbital space tourism.			
X-PRIZE[SM] Competitors (other than those listed elsewhere)													
CAC-1	1999	Advent Launch Services	1	8 Lunar Descent Engines	6 passengers	vertical water launch	horizontal water landing	no	no	Suborbital space tourism. Worldwide passenger service.			Gulf of Mexico
Cosmos Mariner	TBA	Dynamica Research	1	2 Rolls Royce/BMW turbofans 2 JP1/liquid Oxygen engines	3-4 passengers can also carry a 11000 kg payload atop the vehicle this payload could be a booster rocket, allowing insertion of a 900 kg LEO payload	horizontal take-off	horizontal landing	no	no	Suborbital space tourism flights. Launch of LEO satellites using small piggyback payload upper stage. Fast package delivery. High-speed travel.			Ellington Field (Houston)
X Van	TBA	PanAero, Inc. Third Millennium Aerospace	1	4 Rybinsk RD-41 airbreathing lift engines 2 rocket motors	3 passengers to 100 km; Booster for Bantam Van and Space Van (scaled up version)	vertical launch	vertical landing	no	no	Suborbital space tourism.			