1999 REUSABLE LAUNCH VEHICLE PROGRAMS & CONCEPTS

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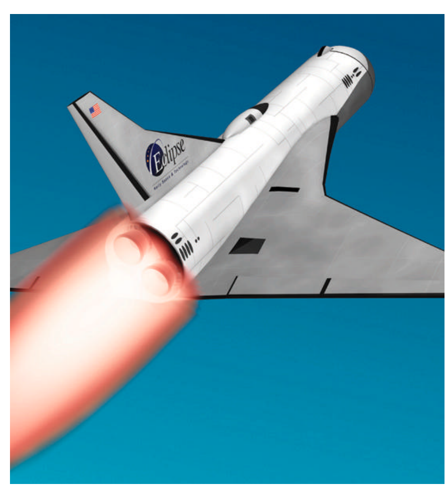
Associate Administrator for
Commercial Space
Transportation (AST)



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Introduction

In January 1998, the Federal Aviation Administration (FAA) Associate Administrator for Commercial Space Transportation (AST) released the first edition of the *Reusable Launch Vehicle Programs and Concepts* sourcebook. The report provided company background, design, and technical information on commercial, government, and international reusable launch vehicle (RLV) programs. The report filled a need for up-to-date, objective information on reusable launch vehicle activities and has become, by far, AST's most popular publication.

The reusable launch vehicle industry made important strides in 1998 towards realizing operational vehicles. Since the first release of this report, several RLV companies have conducted flight and component hardware tests. Others have tests that are scheduled for 1999. Last year, the FAA Associate Administrator for Commercial Space Transportation was given full responsibilities for licensing reusable launch vehicles under the Commercial Space Act of 1998. This report is intended to monitor and report on the progress of this rapidly emerging and growing space industry segment – a segment that could revolutionize space access by achieving lower cost of access to space. This second edition of the sourcebook provides updates on the existing programs and includes information on new programs and vehicles that have been proposed since the release of the 1998 edition.

The United States Government and other governments have been exploring the design and development of RLVs for several decades. During the mid-1990s, however, several small "start-up" companies, staffed with engineers and other technical personnel with years of experience in the aerospace and launch vehicle industries, proposed to develop commercial reusable launch vehicles. Several of these vehicles are being built with the expectation that there will be a boom in demand for launches to low Earth orbit (LEO), primarily of satellites for communication constellations and remote sensing missions. These vehicles also hope to serve other new markets such as passenger service, fast package delivery, space station resupply, and commercial microgravity missions. Some RLVs hope to serve the market for geosynchronous earth orbit (GEO) launches as well. In addition, over a dozen RLV designs are proposed specifically to help foster a market for space tourism that will allow civilians to travel into space.

Also during the 1990s, the National Aeronautics and Space Administration (NASA) decided to proceed with the development of testbed vehicles that would prove technologies and operations concepts for next-generation RLVs. NASA's X-34 and X-33 programs are scheduled to begin flight tests in 2000, while the Future X program will proceed with research on RLV advanced concepts beyond those of the current X-vehicles. NASA hopes that the technologies tested and refined in these programs will be applied to future operational RLVs.

The RLV concepts proposed for development present a variety of launch, landing, and propulsion concepts. Several vehicles employ a "spaceplane" design that takes off and lands horizontally like an airplane, possibly incorporating air-breathing engines for atmospheric flight. These designs generally use upper stages to carry payloads to orbit, while the spaceplane remains on a sub-orbital trajectory.

Several concepts plan single-stage-to-orbit (SSTO) vehicles to deliver payloads directly to orbit, while other vehicles use a multi-stage vertical-launched approach in which each stage returns to Earth for recovery and reuse.

The development of RLVs is driven by the desire to reduce launch costs. A reduction in costs with RLVs is expected because the vehicle is refurbished and reused after each flight rather than replaced (reducing long-term production costs) and because RLVs are designed for quick-turnaround operations that will allow a higher flight rate than with today's expendable vehicles (reducing the cost per flight). Some studies, such as NASA's 1994 *Commercial Space Transportation Study* suggest that reductions in launch costs will enable the emergence and development of new space missions and businesses.

This second edition of *Reusable Launch Vehicle Programs and Concepts* contains several key changes from the original release. Each individual entry has been updated with the most recent publicly available information on the program's financial, technical, testing, and manufacturing progress. Concepts associated with the X PRIZE^{SM} competition are now summarized in an overview table rather than individually. RLV concepts that are largely historical with no current development taking place have been removed from the report.

Following this introduction, the sourcebook provides a chronology of key events in the RLV industry in 1998. The report then divides the RLV programs into four categories: United States Commercial Programs, United States Government Programs, International Concepts, and X PRIZE^{SM} Competitors, providing a summary of publicly available information on each program. Finally, the report contains a summary table of all of the included vehicles that provides company, technical, performance, and market information at a glance.

1998 Developments

Last year saw a number of significant steps toward the development of fully operational reusable launch vehicles (RLVs). Several RLV companies conducted flight and component hardware tests. NASA's X-38 and Kelly Space and Technology's tow-launch concept underwent airborne testing in early 1998. Lockheed Martin Corporation (X-33), Kistler Aerospace Corporation (K-1), Orbital Sciences Corporation (X-34), and Rotary Rocket Company (Roton C-9) all conducted engine tests and completed construction on major vehicle components.

Construction of launch facilities for reusable launch vehicles also continued in 1998. Construction on the X-33 flight test facility at Edwards Air Force Base was completed in November and ground was broken on Kistler Aerospace Corporation's launch facility for Kistler's K-1 reusable launch vehicle at Woomera, Australia. Kistler also signed an agreement last year to use the Department of Energy's Nevada Test Site for possible future launch operations, starting perhaps as early as 2000.

In 1998, the United States Congress deliberated on and passed the Commercial Space Act of 1998, granting the FAA's Associate Administrator for Commercial Space Transportation full authority to license U.S. reusable launch vehicles. The Commercial Space Act of 1998 was signed into law by President William J. Clinton on October 28, 1998. As an immediate response to this authority, AST drafted an interim safety guidance document to inform potential applicants for RLV licenses of the FAA's public safety concerns related to RLV operations. In addition to the draft interim safety guidance, AST began preparing a sample RLV System Safety Program Plan (SSPP) that will demonstrate an approach for addressing safety issues during the design, development, and operation of reusable launch vehicles.

The following chronology summarizes the key events related to the reusable launch vehicle industry in 1998:

- *January* – The Federal Aviation Administration launched a concept of operations to identify how to merge the monitoring and handling of aircraft traffic with rockets and space vehicles that travel to and from space.
- *February 10* – FAA Associate Administrator for Commercial Space Transportation hosted the first annual Commercial Space Transportation Forecast Conference in Arlington, Virginia. Several U.S. commercial reusable launch vehicle companies provided updates on their reusable launch vehicle concepts and discussed the future of commercial space transportation.
- *February* – Kelly Space and Technology completed tow-launch concept demonstration flights. A total of six demonstration flights were conducted between December 1997 and February 1998.
- *March 3* –Platforms International Corporation announced its intent to develop a reusable spaceplane known as the Spaceray.
- *March 4* – NASA's Dryden Flight Research Center successfully completed a cold-flow test flight of the Linear Aerospike SR-71 Experiment.

- *March 9* – Kistler Aerospace Corporation successfully completed a parachute drop test to simulate the return of the K-1 from orbit. The test included the deployment of one of the largest parachute canopy deployments in the world.
- *March 12* – NASA's X-38 vehicle successfully completed its first free-flight drop test. Also, GenCorp Aerojet successfully tested the first AJ-26 (the Aerojet-modified NK-33 Russian engine that will be used on the Kistler Aerospace Corporation K-1). The AJ-26 test firing exceeded the planned launch flight duration of 135 seconds.
- *March 19* – The Commonwealth of Australia granted Kistler Aerospace Corporation environmental approval to establish a launch site in Woomera, South Australia.
- *April 19* – Lockheed Martin installed the aluminum liquid oxygen tank into the X-33 vehicle frame.
- *May* – India's Defense Research Development Organization began initial design work for a small reusable spaceplane known as AVATAR.
- *May* – The Fastrac engine (to be used in the X-34) was assembled and shipped to the Stennis Space Center for testing.
- *May 13* – The FAA hosted an FAA/RLV industry meeting to provide an open exchange of information on RLV licensing and safety issues.
- *May 19* – Bristol Spaceplanes Limited flight-tested a one-fifth scale remotely piloted version of its "Ascender" sub-orbital spacecraft in an attempt to evaluate vehicle control issues.
- *May 20* – The X PRIZE^{SM} Foundation unveiled its X PRIZE^{SM} trophy at the Smithsonian Air and Space Museum. The trophy will be awarded to the first company that builds a spacecraft capable of carrying three people to an altitude of 100 km twice within two weeks.
- *June 17* – Kistler Aerospace Corporation, together with Lockheed Martin Michoud Space Systems, rolled out the first liquid oxygen tank for Kistler's K-1 RLV.
- *June 19* – Rotary Rocket Company broke ground on their $5.5 million Roton manufacturing and flight operations facility.
- *June 23* – Kistler Aerospace Corporation successfully completed a key phase of its parachute drop tests, a six-parachute cluster. Also, the Australian government decided to exempt space launches from a 22-percent wholesale sales tax.
- *July 21* – Rotary Rocket Company began construction of the Roton vehicle.
- *July 23* – Kistler Aerospace Corporation broke ground for its commercial spaceport at Woomera, Australia.
- *July 30* – The first wing assembly for the X-34 technology demonstrator completed qualification tests and was shipped to Orbital Sciences Corporation
- *July 30* – Following approval from the House of Representatives earlier in the year, the Senate passed the Commercial Space Act of 1998 (H.R. 1702).
- *August 31* – NASA contracted with GenCorp Aerojet to produce a de-orbit propulsion module for the X-38 and announces that a space test flight is planned for late 2000 or early 2001.
- *September* – Pioneer Rocketplane completed a full systems design review of the Pathfinder vehicle.
- *September 23* – Burt Rutan's Proteus vehicle was unveiled and test flown in Mojave, California.
- *October* – Kistler announced that the first flight of the K-1 will be held in mid-1999 (this date was later changed to late-1999 or early-2000).

- *October 26* – Kistler Aerospace Corporation signed a final agreement with the Nevada Test Site Development Corporation that grants Kistler the right to occupy and operate from Area 18 at the Nevada Test Site.
- *October 28* – President Clinton signed the Commercial Space Act of 1998 into law.
- *November* – Construction of the X-33 launch facility at Edwards Air Force Base was completed.
- *November 2* – Rotary Rocket Company completed the manufacture of structural components for the Roton vehicle.
- *November 5* – Rotary Rocket Company announced a successful test of its "Whirl Tower." The Whirl Tower is being used to ground test and qualify the rotor landing system for the Roton vehicle.
- *November* 9 – NASA and Lockheed Martin announced that flight tests of the X-33 will be held in December 1999 (this date was modified to mid-2000 in January 1999). Lockheed Martin also announced that it plans to establish a company to develop VentureStar™, contingent on the results of the X-33 program.
- *November 23* – Rotary Rocket Company announced the completion of the injector development program for its Rotary RocketJet Common Core Combustor.
- *December 1* – Rotary Rocket Company completed a successful first centrifugal pumping test. The centrifuge was used to ground test and qualify Rotary RocketJet powerplant components and sub-assemblies for the Roton vehicle.
- *December 8* – NASA selected Southwestern Research Institute, Draper Laboratory, AeroAstro, the Lewis Research Center, the Marshall Space Flight Center, and the Ames Research Center to conduct Future X Pathfinder experiments, and signed an agreement with Boeing to develop the Advanced Technology Vehicle flight testbed for the Future X Trailblazer program.

Overview of Development Programs

This report divides RLV programs into four categories: United States Commercial Programs, United States Government Programs, International Concepts, and X PRIZE℠ Competitors. This is a compilation of known RLV programs and concept development efforts worldwide.

United States Commercial Programs include vehicles under development that will perform both payload launch and human passenger/crew missions. Most of the concepts in this section have been forwarded by small private companies with plans to launch satellites into low Earth orbit. Some systems, however, are also planning to provide flights for space tourists. Also included is Lockheed Martin's proposed VentureStar™ vehicle that is envisioned to support a variety of space launch missions.

United States Government Programs include testbed vehicles and other programs intended to advance the state-of-the-art technologies for advanced space transportation concepts such as RLVs. NASA has begun flight testing of prototypes in the past year and will commence flight test of its main RLV concept vehicles, the X-34 and X-33, in 2000. NASA will continue to develop RLV technologies through research programs and testbed vehicles. The United States Air Force (USAF) also has plans to explore the development of a spaceplane concept and has engaged in some preliminary testing of a demonstration vehicle.

International Concepts include proposed vehicles from both government and commercial organizations. The governments of Japan and India are proceeding with long-range plans for RLV development, while Bristol Spaceplanes Ltd. in Great Britain is developing commercial vehicle concepts. Although other long-proposed European concepts were addressed in the first edition of this report, significant progress for those designs now appears unlikely in the foreseeable future.

X PRIZE℠ Competitors are presented separately from the other commercial vehicles because of the unique nature of their intended mission. The X PRIZE℠ competition will award a $10 million prize to the first entrant that proves it can carry at least three people to a 100-km altitude and repeat the flight within two weeks. X PRIZE℠ vehicles are specifically designed to accomplish this mission, although some X PRIZE℠ vehicles plan follow-on vehicles for commercial satellite launch missions. There are currently 15 entrants in the competition. Two entrants, Kelly Space and Technology and Pioneer Rocketplane, are focused primarily on satellite launch missions and therefore have been included in the United States Commercial Programs section of this report.

Vehicle Name	Manufacturer / Developer	First Launch	Description
Commercial Programs			
Astroliner	Kelly Space and Technology	2002	Based on the Eclipse tow-launch technique; RLV is air-launched by modified transport aircraft; RLV proceeds on sub-orbital trajectory and lands horizontally
K-1	Kistler Aerospace Corporation	1999 / 2000	Two-stage vertically launched vehicle with recoverable stages using parachutes and air bags
Pathfinder	Pioneer Rocketplane	2000 / 2001	Horizontal-takeoff spaceplane concept using air-to-air refueling techniques to acquire liquid oxygen fuel for reaching space
Roton C-9	Rotary Rocket Company	2000	Single-stage-to-orbit vehicle which uses centrifugal pumping engine for vertical takeoff; uses rotor blades powered by small rocket motors to land vertically
SA-1	Space Access LLC	2001	Unpiloted spaceplane using hybrid propulsion system to reach space, where it deploys upper stages for carrying satellites
Space Cruiser System	Vela Technology Development	2001	Two-stage piloted spaceplane used for sub-orbital flights; uses horizontal-takeoff-and-landing design
VentureStar™	Lockheed Martin Corporation	2004	Commercial follow-on to X-33; single-stage-to-orbit vehicle that takes off vertically and lands horizontally
United States Government Programs			
X-33	Lockheed Martin Skunk Works	2000	RLV testbed to demonstrate single-stage-to-orbit, high supersonic speeds, and autonomous operations capabilities
X-34	Orbital Sciences Corporation	2000	RLV testbed to demonstrate RLV operations, such as fast turnaround, landing in varying weather conditions, and safe abort procedures
Future X Trailblazer	Boeing	TBA	Advanced space transportation technology program for demonstrating mission-specific RLV designs and testing vehicle prototypes
Future X Pathfinder	Several companies and NASA Centers	TBA	Advanced space transportation technology program for validating specific RLV technologies
X-38/Crew Return Vehicle	Scaled Composites/TBA	2000	Reusable emergency crew return vehicle to be attached to the International Space Station (X-38 is prototype test vehicle)
Military Spaceplane	Boeing, Lockheed Martin Corporation	TBA	Two-stage spaceplane concept; reusable orbital Space Maneuver Vehicle deployed by a sub-orbital reusable first stage
International Concepts			
AVATAR	Defense Research Development Organization (India)	TBA	Small reusable spaceplane designed to take off and land horizontally
HOPE-XA Spaceplane	National Space Development Agency (Japan)	2001	Reusable crewless spaceplane launched from Japanese H-2A expendable launch vehicle
SSTO Spaceplane	National Aerospace Laboratory (Japan)	2010	Crewed single-stage-to-orbit spaceplane designed to take off and land horizontally
Spacecab/ Spacebus	Bristol Spaceplanes Ltd. (United Kingdom)	2010	Reusable orbiters launched from supersonic aircraft used as first stage; both stages land horizontally

In addition to the programs described in detail in this report, there are three additional RLV concepts under consideration for development, but for which limited information is available. In March 1998, Platforms International Corporation, a developer of software for crewless aerial vehicles, proposed the Spaceray, a spaceplane capable of carrying an expendable booster for satellite launches. Platforms International has entered into a strategic partnership agreement with "some of the leading aerospace companies in Russia" for the development of the Spaceray system.[1] In another program, the Russian aerospace company Molniya is reportedly developing the Molniya Multipurpose Aerospace System (MAKS), which consists of a spaceplane that would be air-launched from the back of an AN-124 transport aircraft. The MAKS would be able to carry 9000 kg to orbit.[2] Finally, in September 1998, researchers from Lawrence Livermore National Laboratory presented the Hypersoar multipurpose hypersonic vehicle that skips atop the atmosphere. The researchers indicated that the Hypersoar could be used for high-speed atmospheric missions or as the first stage of a space launch system.[3]

United States Commercial Programs

The private sector 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.

Kelly Space and Technology – Astroliner

Kelly Space & Technology (KST) is developing the Astroliner reusable launch vehicle based on their patented tow-launch technique. Kelly Space & Technology was co-founded by former TRW colleagues Michael Kelly and Michael Gallo in 1993. The Astroliner will be towed into the air by a modified Boeing 747 aircraft, where the RLV will be released and proceed on a sub-orbital trajectory under its own power. Astroliner will then use expendable upper stages to inject payloads into orbit.

Vehicle: Astroliner (shown above)

Developer: Kelly Space and Technology

First launch: 2002

Number of stages: 3-4 (including towing aircraft)

Possible launch sites: Atlantic City, NJ; Vandenberg AFB, CA; White Sands Missile Range, NM

Markets served: Launch of LEO constellation satellites.

Funding: Program is seeking funding. Some private funding secured.

The Astroliner, measuring 38 meters in length, will be powered by a reusable 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 125 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 then reenters the atmosphere and returns to land at a conventional airfield under the guidance of its two-pilot crew.[4] The Astroliner design also features wing-mounted jet engines for powered descent and landing.

The Astroliner will use expendable upper stages, solid or liquid depending upon mission requirements, to carry payloads from the vehicle into low Earth orbit (LEO), medium Earth orbit (MEO) or geosynchronous transfer orbit (GTO). The Astroliner baseline design uses selected upper stages to launch a pair of Motorola replacement Iridium satellites. Other, more powerful upper stages, such as the Star 75, Pratt and Whitney's Orbus 21, and other liquid stages are used for launching heavier LEO payloads of up to 4550 kg.[5]

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 some of the infrastructure required for vertical launch vehicles. KST also claims that it will offer launch prices of about $15 to $25 million (or about $2000 per pound to LEO) and reduced launch insurance rates for Astroliner payloads.[6] KST signed a contract in October 1996 with Motorola to launch 20 replacement satellites for the Iridium constellation in 10 as-needed launches.[7]

From December 1997 to February 1998, KST successfully conducted the Eclipse Experimental Demonstration (EXD) tests in cooperation with NASA's Dryden Flight Research Center and the USAF Flight Test Center at Edwards Air Force Base in California. These ground and flight tests demonstrated the Eclipse tow-launch technique using a modified QF-106 aircraft (provided by the USAF), and a USAF Flight Test Center-supplied C-141A tow aircraft. KST also received a matching grant from the state of California to conduct research associated with the EXD program. In all, six flight demonstrations were conducted.[8] Current plans call for the first launch of the Astroliner in 2002.

Kistler Aerospace Corporation – K-1

Kistler Aerospace Corporation is developing the K-1 two-stage reusable launch vehicle for commercial launches of LEO payloads. Kistler was founded in 1993 by Walter Kistler, whose background includes founding several technology companies, and Bob Citron, the founder of Spacehab Inc.

The K-1 design was developed in 1995 and 1996 as a two-stage-to-orbit (TSTO) vehicle that will have a payload capacity of 10,000 pounds to a standard LEO and will offer launch prices of about $17 million per launch.[9] Kistler signed an agreement potentially worth more than $100 million in January 1997 with Space Systems/Loral to provide ten launches aboard the K-1.[10]

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 36.9 meters high, with a launch mass of about 380,000 kg.

Vehicle: K-1

Developer: Kistler Aerospace Corp.

First launch: 1999 or 2000

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 some private funding, but is seeking additional funds to complete the project.

Kistler's K-1 vehicle employs off-the-shelf technology and components in its design. The first stage, known as the "Launch Assist Platform," is powered by three liquid oxygen (LOX)/kerosene GenCorp Aerojet AJ-26 series engines. These engines include the core of the NK-33/NK-43 engines originally built in the 1960s for the Russian moon mission program. At 121 seconds after launch, the Launch Assist Platform separates from the second stage and restarts its center engine to fly a return trajectory to a predetermined landing area near the launch site. The Launch Assist Platform deploys parachutes and descends to the 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. The Orbital Vehicle is powered by a single Aerojet AJ-60 engine (derived from the Russian NK-43 engine). The Orbital Vehicle also carries LOX/ethanol thrusters for orbital maneuvers and a nitrogen cold gas system for attitude control. Following payload separation, the orbital vehicle continues on orbit for about 24 hours, after which the LOX/ethanol maneuvering system de-orbits the vehicle. After atmospheric re-entry, the orbital vehicle flies a guided re-entry path to a pre-determined landing area near the launch site and deploys parachutes and air bags for touchdown.

Kistler's subcontractors are producing the major components of the vehicle, and several major milestones were accomplished in 1998. Northrop Grumman Corporation has been contracted to provide the vehicle structure and, as of January 1999, had completed 21 of the 23 major structural panels for the K-1.[11] Aerojet has imported 46 Russian-made NK-33 and NK-43 engines for use in the K-1 propulsion system.[12] In March 1998, Aerojet completed the first test firing of the modified NK-33; the firing lasted 145 seconds, 10 seconds longer than will be required in the K-1 flight profile.[13] As of January 1999, five additional tests had been successfully completed.[14] In June 1998, Irvin Aerospace successfully tested the parachute system for the K-1 first stage by drop-testing a 88,000 kg pallet simulating the first stage from an altitude of 3 km. The test instrument deployed a cluster of six parachutes and landed safely, paving the way for four other successful drop tests by the end of January 1999.[15] Also in June, Lockheed Martin Michoud Space Systems, which is building five sets of the first and second stage K-1 LOX tanks, delivered the first of the first-stage LOX tanks.[16] In October 1998, Kistler announced that development of the flight control software by Draper Laboratory and Allied Signal was "95% complete."[17] Final vehicle assembly commenced in May 1998, as technicians began to put together the first stage mid-body.

In August 1997, the United States Department of Energy signed an agreement with the Nevada Test Site Development Corporation (NTSDC) that would allow Kistler to develop launch operations at the site.[18] In October 1998, Kistler finalized the deal with NTSDC to permit Kistler to occupy a segment of the Nevada Test Site (NTS) for its launch operations.[19] Kistler is in pre-application processing with the FAA for permission to conduct launches from the NTS, with both stages returning to Earth at the NTS as well.

In 1998, Kistler also decided to construct a launch facility at the Woomera site in South Australia for both test and launch operations.[20] Kistler received authorization from the Australian government to begin construction of launch facilities at Spaceport Woomera in April 1998 and held a ground-breaking ceremony at the site in June 1998.

By the end of 1998, Kistler reportedly had raised over $450 million of the $750 million needed to build five K-1 vehicles and the two spaceports.[21] In January 1999, Kistler announced that the first K-1 launch is expected in late 1999 or early 2000. Construction of the spaceport at Woomera and some vehicle assembly work will be slowed until Kistler can secure additional financing.[22]

Pioneer Rocketplane – Pathfinder

Vehicle: Pathfinder

Developer: Pioneer Rocketplane

First launch: 2000 or 2001

Number of stages: 2

Possible launch sites: Vandenberg AFB

Markets served: Launch of small and medium-class LEO payloads.

Funding: Program has secured some private funding and is seeking additional funds.

The Pathfinder (not to be confused with the Future X Pathfinder program discussed in the U.S. Government Programs section) tracks its heritage to a military spaceplane concept.[23] 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.

Mr. Burnside 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.[24] Pioneer Rocketplane advanced the concept (renamed the Pathfinder) as a potential design for NASA's X-34 program.

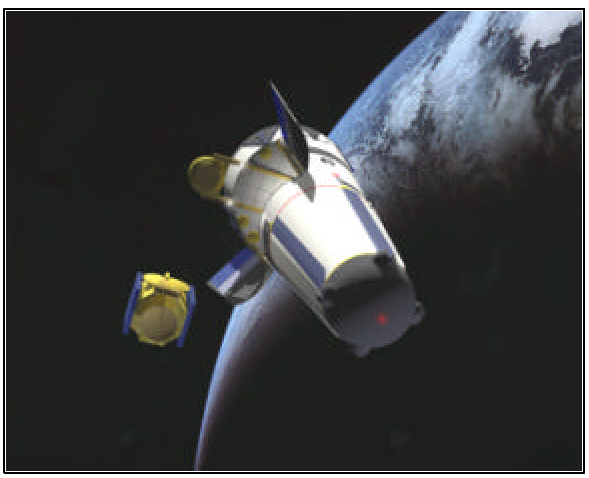
Although the Pathfinder was not selected for the X-34, its proponents elected to continue Pathfinder development. In June 1997, Pioneer Rocketplane was awarded one of four $2 million NASA Low Cost Boost Technology (Bantam) Program contracts to develop detailed preliminary designs and conduct wind-tunnel tests for concepts to launch small satellites. The Low Cost Boost Technology program was later canceled.

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. 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.

On satellite launch missions, the Pathfinder would ignite its RD-120 rocket engine following the LOX transfer, carrying it to a speed of Mach 12 and an altitude of about 130 km. The vehicle would then release a satellite payload mated to a conventional upper stage from its payload bay. The payload would be carried into orbit by the upper stage, with the Pathfinder returning to the atmosphere. After deceleration to subsonic speeds, the Pathfinder would re-start its jet engines and land horizontally.[25]

The Pathfinder vehicle uses primarily existing technology and components. The propulsion system uses proven jet and rocket engines (two GE F404 turbofan engines and one kerosene/oxygen-burning RD-120 rocket engine), and the avionics systems are derived from existing military aircraft. In September 1998, Pioneer Rocketplane announced that it had completed a system design review for the Pathfinder that indicated that all components and systems fit together properly.

Pathfinder is expected to cost about $275 million to develop. Pioneer Rocketplane is currently seeking investors for the effort and had secured commitments for over $3 million by December 1998.[26]



Rotary Rocket Company – Roton C-9

Roton C-9 is the latest design from the Rotary Rocket Company, introduced in mid-1998.[27] A previous design was unveiled at the Cheap Access To Space Symposium in July 1997. Although several major design changes were made from the C to the C-9, the Roton concept remains based on the 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.

The SSTO Roton C-9 vehicle is designed for vertical takeoff and landing. The 19.5-meter high Roton C-9 is powered by a proprietary design Rotary RocketJet engine that rotates inside the base of the cylindrical vehicle. The rotation feeds the LOX/kerosene propellants into the combustors (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, the Roton C-9 could deploy a satellite payload and perform a de-orbit burn. The vehicle can remain on-orbit for up to 72 hours.

Vehicle: Roton C-9
Developer: Rotary Rocket Company
First launch: 2000
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 $30 million in private funding.

During 1998, the Roton vehicle concept underwent design changes in appearance and configuration. The current vehicle design, the Roton C-9, is cone-shaped with the rotor blades folded flat against the exterior. The Roton C-9 uses rotor blades to control the vehicle descent, each of which are powered by small hydrogen peroxide/methanol rocket motors on the blade tips to allow the vehicle to come to a complete stop before landing. The cargo compartment on the Roton C-9 is positioned in the middle of the vehicle between the LOX tank (in the nose) and the kerosene tank (above the engine).

The Roton touches down vertically under the control of its two-person crew. The vehicle is designed to be serviced by a small team of ground personnel, and Rotary Rocket is targeting turnaround times between flights of 24 hours or less.[28] The Roton also has been designed to be able to return to Earth with the cargo bay fully loaded.

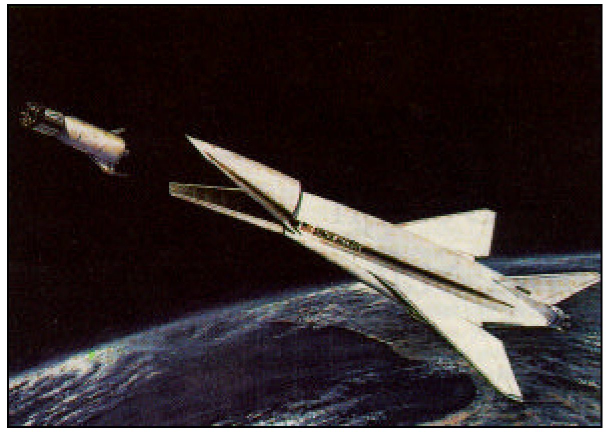
Rotary Rocket Company is currently raising funds for the development of the Roton C-9 and has contracted with several other firms for component construction. As of July 1998, Rotary Rocket had raised $17 million in investment funding and had contracted Barclays Capital to serve as financial advisors and placement agency for an approximately $20 million private equity placement.[29] January 1999 reports indicated that Rotary Rocket had raised a total of $30 million in funding.[30]

Rotary Rocket Company performed tests of many of its systems throughout 1998 and plans to continue its testing in 1999. In June 1998, Rotary Rocket successfully hot-fired the thrusters it plans to use for the Roton's reaction control system and for the vehicle's rotor blade-tip engines. In November, Rotary Rocket conducted a successful ground test of the rotor landing system for the Roton and completed the development of the "Common Core Combustor." A total of 72 Common Core Combustors will make up the RocketJet engine that will power the vehicle to orbit. In December, Rotary Rocket conducted a successful ground test of the centrifugal pumping system for the RocketJet powerplant. In addition, the company began construction of its manufacturing and flight operations facility in June 1998 at the company's Mojave Airport site and completed the construction in January 1999.[31]

Rotary Rocket Company will conduct landing tests using the Roton Atmospheric Test Vehicle (ATV), in the second quarter of 1999. The ATV is currently being assembled, after Rotary Rocket's November 1998 announcement that Scaled Composites had completed construction of the structural components for the vehicle. The ATV is a full-size prototype vehicle without the RocketJet engine. The ATV will use its rotor tip rockets to fly to 10,000 feet and then conduct approach and landing tests.[32]

Construction of the first Roton Propulsion Test Vehicle (PTV) will begin in the summer of 1999. Sub-orbital flight tests are planned for early 2000, with orbital flights and commercial operations targeted for later that year.[33]

Space Access LLC – SA-1



Vehicle: SA-1

Developer: Space Access LLC

First launch: 2001

Number of stages: 2-3 (depending on payload requirements)

Possible launch sites: TBA

Markets served: Launch of LEO and GTO payloads.

Funding: Program has secured some private funding.

The SA-1 has been proposed to conduct satellite launches by Space Access LLC. The concept consists of an unpiloted spaceplane that uses a hybrid propulsion system and one or two rocket-powered upper stages to deliver a full range of payloads to LEO or GTO.

Until early 1998, the Palmdale, California-based Space Access had been developing its system in near-secrecy. Space Access president Stephen Wurst indicated in early-1998 interviews that publicity was not necessary because Space Access already had sufficient funding and because the company wanted to keep its development plans and partner structure proprietary.[34]

The spaceplane vehicle, or "aerospacecraft," is approximately the size of a Boeing 747 aircraft. Its propulsion system is based on a ramjet engine design that was developed in the 1960s by the USAF. Space Access has developed a proprietary modification to the engines that will allow the ramjet to operate at both subsonic and supersonic speeds (ramjets normally only operate above Mach 2).[35] One of the company's subcontractors, Kaiser Marquardt, has reportedly tested elements of the propulsion system,[36] and Space Access has worked with the Air Force Research Laboratory (AFRL) since September 1995 to study the "ejector" ramjet propulsion system and the design of the aerospacecraft. As of March 1998, Space Access had wind-tunnel tested the ejector ramjet engine at all of the altitude and speed points of the SA-1's planned flight profile.[37]

The SA-1 vehicle will take off horizontally, using a mixture of air and liquid hydrogen to power its ejector ramjet engines. The vehicle pitches up at high altitude and uses a liquid rocket to exit the atmosphere. The vehicle then releases an upper stage carrying the satellite payload from its nose area. For LEO missions, the SA-1 carries a single upper stage that features a lifting-body design and autonomously de-orbits and lands horizontally following satellite deployment. For missions to geosynchronous transfer orbit, the SA-1 carries two such upper stages.[38]

Space Access reportedly has secured funding from several large investors, and has formed strategic partnerships with "several major aerospace companies." Space Access plans to test a one-third-scale demonstrator vehicle with the ejector ramjet and other key systems. Development plans call for testing of a full-size vehicle in 2001 with launch operations commencing in 2002.[39]

Vela Technology Development – Space Cruiser System

Vehicle: Space Cruiser System (second stage spaceplane pictured)

Developer: Vela Technology Development, AeroAstro LLC

First launch: 2001

Number of stages: 2

Possible launch sites: Commercial airports

Markets served: Sub-orbital space tourism flights.

Funding: Program funding is not known.

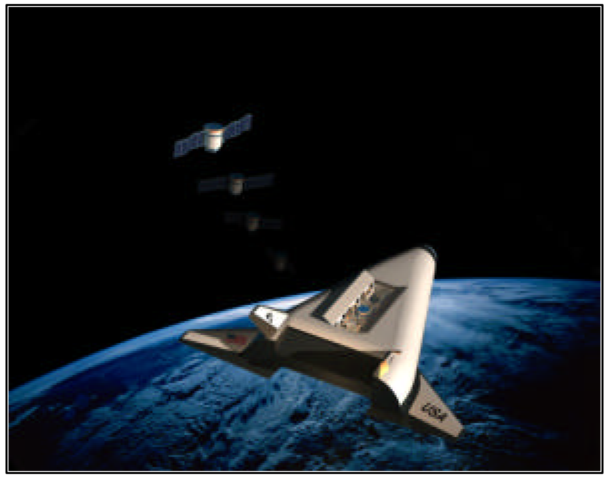
The Space Cruiser System (SCS) vehicle is currently being marketed for space tourism flights beginning in December 2001 by Zegrahm Space Voyages, a division of the Zegrahm Expeditions travel company. The SCS vehicle is being designed and developed by Virginia-based Vela Technology Development, Inc. to carry six passengers on a sub-orbital flight reaching just over 100 km in altitude.[40]

The Chairman and CEO of Vela Technology Development is Larry Hecker. Mr. Hecker 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.[41]

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 where the Space Cruiser, carrying two crew members 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 the vehicle's descent and then will activate two JT15D-class turbo-jet engines to return to a landing site.[42]

Vela Technology Development intends to build two sets of operational vehicles and plans to initially operate two launches per week. In November 1997, Vela named AeroAstro LLC as the prime contractor for the SCS system.[43]

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.

VentureStar™ is Lockheed Martin's potential commercial follow-on to the X-33 vehicle being developed for NASA's RLV program (a complete overview of the X-33 is provided below).

In 1993, Lockheed Skunk introduced a concept vehicle using an aerospike engine and a wedge-shaped lifting-body design known as an "aeroballistic rocket" (a VentureStar™ forerunner). This design concept was offered for the USAF's planned new vehicle program called "Spacelifter." Spacelifter was canceled, however, in the wake of the USAF's commitment to the Evolved Expendable Launch Vehicle (EELV) program. VentureStar™ resembles the original aeroballistic rocket in the lifting-body design.

The VentureStar™ vehicle will be similar in design to the X-33 but twice the size and about eight times the launch mass. VentureStar™ will be powered by seven linear aerospike engines, while the X-33 employs two of these powerplants.

Lockheed Martin plans to target the commercial satellite launch market with VentureStar™. Lockheed Martin hopes to operate at a flight rate of 40 launches per year, leading to launch costs of approximately $1000 per pound. NASA and Lockheed Martin are also studying the accommodation of crew missions on VentureStar™. One option is to launch VentureStar™ as a cargo-only craft initially, with crew-capable modules phased in later.[44]

Development of VentureStar™ is underway in parallel with the X-33, and Lockheed Martin plans to build two VentureStar™ vehicles. Lockheed revealed in late 1998 that it plans to establish a company in 1999 to develop VentureStar™.[45] Jerry Rising, vice president for Lockheed Martin's X-33/RLV program stated, however, that VentureStar™ development is still contingent upon the results of the X-33 testing program.[46]

Lockheed Martin plans to contract for the use of two spaceport facilities for VentureStar™ operations. In July 1998, Lockheed Martin provided its spaceport requirements for the VentureStar™ to interested states. Fifteen states responded to the qualifications, and final selection should be made by the end of 1999.[47]

United States Government Programs

In the 1990s, NASA and the Department of Defense 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. NASA is also participating in a joint effort with the European Space Agency (ESA) for a crew return/crew transfer vehicle for the Space Station. NASA will continue RLV technology development beyond the X-33 and X-34 programs with the Future X program. The U.S. military is continuing its RLV study with the development of military spaceplane concepts.

X-33

Following the National Space Transportation Policy announced in 1994, NASA announced the RLV program and solicited proposals for the SSTO X-33 experimental demonstrator.

The X-33 program was initiated to develop a testbed for integrated RLV technologies, paving the way for full-scale development of a SSTO reusable launch vehicle that would be contracted for government and private sector use.[48] 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 turnaround time and a 3.5-hour emergency flight turnaround time. NASA hopes the program will lead to the development of RLVs that will reduce the cost of space launches by an order of magnitude within ten years.

Vehicle: X-33

Developer: Lockheed Martin Skunk Works

First launch: 2000

Number of stages: 1

Possible launch sites: Edwards Air Force Base, CA

Markets served: Testbed for RLV technologies and operations.

Funding: The approximately $1.1 billion project is funded under NASA's RLV Program. NASA will contribute about 80% and Lockheed Martin will contribute about 20%. Costs of program delays are borne by the contractors.

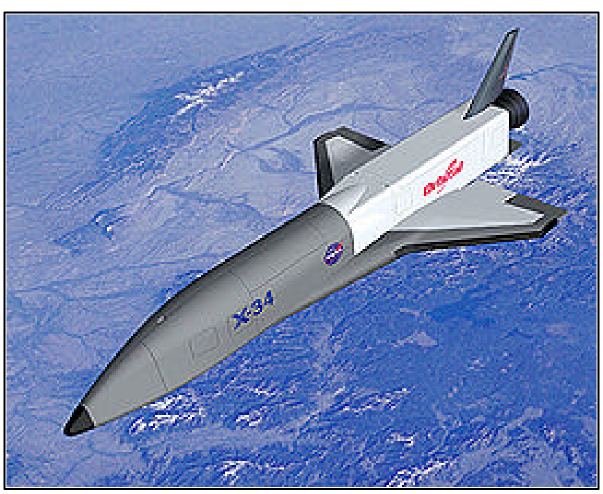
In April 1995, NASA signed cooperative agreements with Lockheed Martin, McDonnell Douglas, and Rockwell International to develop concept designs for the X-33 program. Lockheed Martin offered a vertical-takeoff, horizontal-landing concept based on the aeroballistic rocket/VentureStar™ design (see the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

On July 2, 1996, NASA selected Lockheed Martin's design. NASA will provide about 80% of the approximately $1.1 billion cost, while Lockheed Martin is expected to about 20%. Payment, however, is based on meeting progress milestones during development.

Lockheed Martin's design is a 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 will be powered by two linear aerospike engines under development by Boeing's Rocketdyne division that do not use conventional cone-shaped exhaust nozzles but allow the exhaust flow to adjust to changes in atmospheric pressure.

The X-33 is currently under construction at Lockheed Martin's Skunk Works facility. In November 1997, the vehicle passed a critical design review, a key step before actual construction began. In early 1998, designers were wrestling with weight and design stability problems with the vehicle. The design team made significant strides in dealing with these questions by reducing the ballooning weight and modifying the design of the fins and vertical stabilizers.[49] The liquid oxygen tank was fitted into the vehicle frame on schedule in April 1998, and the thermal protection system completed its qualification testing in October.[50] Final assembly of the liquid hydrogen tanks is underway, and the tanks will be sent to Marshall Space Flight Center for testing before being mated to the vehicle. Flight tests of the linear aerospike engine atop an SR-71 aircraft took place early in 1998. Testing of the linear aerospike engine powerpack (the main power generating and pumping components) at the Stennis Space Center occurred from October through December. Testing has been successful, and the flight engines are scheduled to be delivered in September 1999. Flight tests are currently scheduled to begin mid-2000.[51]

The flight test facility at Edwards Air Force Base in California was also completed in November 1998. 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 to landing sites at Michael Army Air Field in Utah and Malmstrom Air Force Base near Great Falls, Montana. The X-33 will fly to a maximum altitude of about 91 km at a maximum speed of about Mach 13.8.



X-34

In 1994, in addition to the X-33 program, NASA announced the X-34 program to develop an RLV for payloads of about 1100 kg. After first awarding a contract to a team of Orbital Sciences and Rockwell International in 1995, NASA canceled the contract and redesigned the X-34 program to use a smaller vehicle to demonstrate key technologies. Following a competition that included nine entries, NASA awarded Orbital Sciences Corporation a $60 million contract in June 1996 to design,

Vehicle: X-34

Developer: Orbital Sciences Corporation

First launch: 2000

Number of stages: 1

Possible launch sites: White Sands Missile Range, NM

Markets served: Testbed for RLV technologies and operations.

Funding: Project is funded for about $85 million under NASA's RLV Program.

develop, and test the X-34.

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 turnaround, 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.[52]

The X-34 design features a cylindrical body with delta wings. The vehicle 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 (similar to Orbital Sciences' Pegasus expendable launch vehicle). The primary engine is a new LOX/kerosene rocket engine known as Fastrac, that is being designed, developed, and provided by NASA under a separate program. The X-34 design, however, will allow for easy substitution of engines.[53]

In May 1997, the X-34 completed a system design freeze, allowing production to begin. After undergoing tests at Marshall Space Flight Center, the initial complete engine was assembled in May 1998 and was shipped to Stennis Space Center for testing in June.[54]

In January 1998, NASA modified its contract with Orbital Sciences to include the production of a second X-34 vehicle. The addition of the second vehicle reduces the risk to the program should one vehicle be damaged or destroyed during testing.[55] The first unpowered flight of the vehicle is now scheduled for fall 1999, with powered flights beginning in early-2000.[56] Orbital is constructing an unpowered testbed vehicle, which will be followed by the two powered X-34 craft.

NASA plans to have an additional type of engine available for the X-34 program. The Russian-heritage NK-39 (a smaller version of the NK-33 engine used for the Kistler Aerospace Corporation K-1 program) will be modified by GenCorp Aerojet for use in the X-34 vehicles. NASA decided to make the additional engine available to keep the program on schedule should the Fastrac engine be further delayed and to perform certain flight tests. The Fastrac engine is not designed to hold the vehicle at a constant speed (its thrust cannot be adjusted in flight), but such a capability is required for some of the planned flight test profiles for the X-34. The replacement of the Fastrac with the NK-39 for these flights will allow the testing team to conduct these experiments.[57]

The first phase of the test program calls for two test flights at speeds up to Mach 3.8. In December 1998, NASA decided to exercise its option for a second phase of 25 additional X-34 flights. These flights will achieve a range of different speeds and operate in a variety of conditions to test RLV flight technologies. This option brings the total value of the contract with Orbital Sciences to about $85 million.[58]

Future X Program

Following the award of the X-33 contract, NASA attempted to determine whether to continue creating experimental vehicles and, if so, which future experimental vehicles (or X-vehicles) to fund. To this end, NASA developed the Future X program for long range technology development and established two classes of X-vehicles (Trailblazer and Pathfinder).[59] New X-vehicles that will be developed as technology concepts are presented from the Advanced Space Transportation Program, as demand for development of a concept is expressed by potential users and as funding becomes available. About $90 million in funding for the experimental programs is expected through 2002.[60]

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 funded for $90 million through 2002.

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 funded for $90 million through 2002.

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 turnaround 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.[61]

The Future X Pathfinder program will develop programs that focus on validating specific technologies (in contrast to the Trailblazer program, which will develop integrated vehicle prototypes). The Pathfinder projects respond to the need to test new technologies with 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.[62]

Over the summer of 1998, NASA's Advanced Space Transportation Program sought proposals for several Pathfinder technology development and demonstration projects each worth less than $1 million.

In addition, it called for proposals for one Trailblazer flight test vehicle. About 50 proposals were received.

In early December 1998, NASA selected several companies and three NASA research centers to participate in the development of Future X experiments.[63] NASA selected Boeing for negotiations for a cooperative agreement to develop a Trailblazer flight testbed vehicle called the Advanced Technology Vehicle (ATV) that would develop 29 technologies. No firm vehicle design has yet been selected, but the X-40A testbed vehicle developed for the Military Spaceplane Program (see Military Spaceplane entry below) may be a potential design for the ATV.

Companies selected under the Future X program for Pathfinder programs include Southwestern Research Institute ($2.5 million), which will demonstrate new in-space propulsion; Draper Laboratory ($0.75 million), which will provide an autonomous abort landing experiment; and AeroAstro ($0.8 million), which will demonstrate technologies that will reduce space access costs for small payloads.

In addition, NASA's Lewis Research Center, Marshall Space Flight Center, and Ames Research Center will conduct demonstration experiments. The Lewis Research Center will demonstrate propulsion technologies for cryogenic upper stages ($4.3 million). Marshall Space Flight Center will conduct experiments on an electrodynamic tether that provides space propulsion without propellant ($6.6 million). The Ames Research Center will examine technologies for an integrated vehicle health-management system ($4.5 million) and ultra-high temperature ceramics ($4.2 million).

X-38/Crew Return Vehicle

The X-38 is a technology demonstration vehicle project of the Johnson Space 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 a means of returning to Earth if an emergency requiring immediate evacuation of the Space 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.

Plans for a CRV have been under consideration since the Space Station was first proposed. Proposals for CRVs have taken on many different forms. 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.

Vehicle: X-38/CRV

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

First launch: 2000 (atmospheric tests in 1998)

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 three atmospheric and one space test vehicles.

CRV development is expected to cost almost $1 billion, with ESA contributing about 30 percent.[64] ESA and the Deutschen Zentrum für Luft - und Raumfahrt (DLR, or German National Aerospace Research Center) are engaged in a cooperative effort with NASA to develop the X-38 test articles for the CRV program. European participation in the program underwent turmoil in October 1997, as France decided to terminate its funding for the program, but multinational participation remained strong in 1998 as the French company Dassault provided critical design support, and Dutch, German, and Spanish companies produced key components.[65]

The X-38 employs a lifting body design based on a 1970s-vintage X-aircraft (the X-24A). Rather than landing in an unassisted glide like the Space Shuttle, the X-38 will deploy a steerable parafoil that will allow the vehicle to maneuver to a landing site. The parafoil is as large as the wing area of a Boeing 747 aircraft.

Four X-38 vehicles are planned, including three atmospheric prototypes and one orbital test vehicle. Two X-38 atmospheric prototypes 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. The third atmospheric prototype will undergo construction in 1999, and the orbital test vehicle is currently being developed at the Johnson Space Center.

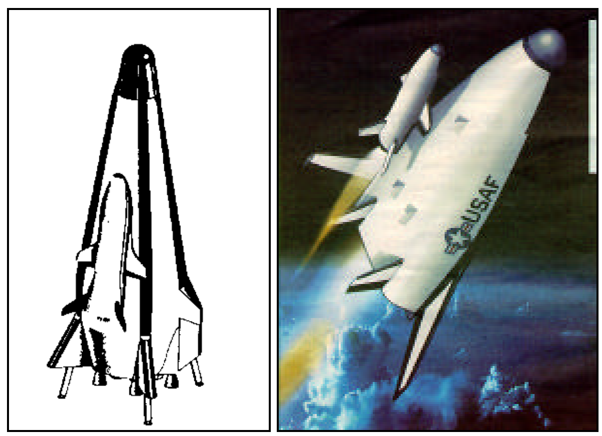
Although the X-38 is not designed to be an RLV (that is, it is not intended to be a launch vehicle), ESA and NASA have agreed to develop a final design that is compatible for launch atop an ELV such as Ariane 5.[66] This decision required that the designs of the third prototype and the orbital test vehicle be modified to be able to withstand the structural pressures of launch. 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. NASA's Johnson Space Center is planning to release a solicitation for proposals for the CRV in early 1999. NASA officials have decided that regardless of which contractor is awarded the design and construction contract for the CRV, the vehicle will have to conform to the design specifications developed by the X-38 program.[67]

The first prototype conducted drop tests during 1998, during which the vehicle was dropped from the wing of a B-52 and returned to the ground using its parafoil. Following the completion of its testing, the first vehicle was returned to Scaled Composites to be retrofitted to the redesigned aerodynamic shape. The second is scheduled to conduct a series of flights starting in February 1999. The second vehicle will have a flight control system that will allow it to test maneuvers following its drop from the B-52. The third prototype is intended to become the primary atmospheric test vehicle after the turn of the century. The orbital test vehicle is scheduled for launch on the Space Shuttle Columbia in November 2000. Both the third prototype and the orbital vehicle will be the same size and shape as the planned operational CRVs.[68] NASA has contracted with GenCorp Aerojet to design and produce a de-orbit propulsion module for the X-38. The first space flight test for the X-38 with its de-orbit stage is planned for late 2000 or early 2001.[69]

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 sub-orbital 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.[70]

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 conducted 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 uncertain.

Following a year of study, the AFSPC followed the ICT'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.[71] 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 sub-orbital reusable first stage. The SMV is released and accelerates to orbit, where it will be designed 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 USAF'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 offered a concept based on its X-33 design, while McDonnell Douglas (now Boeing) proposed a concept based on the Clipper

Graham.[72] The Clipper Graham was McDonnell Douglas' single-stage vertical-takeoff-and-landing RLV concept that was tested by the USAF and later NASA from 1993 to 1996.

The SMV is under development by Boeing Phantom Works, and a 90-percent scale unpowered testbed, also known as the X-40A, was rolled out in September 1997 under a $5.2 million contract awarded in October 1996 by the USAF's Wright Laboratory.[73] The first flight of the X-40A took place on August 11, 1998, when it was carried aloft by helicopter and released, making a landing controlled by the vehicle's on-board systems.

The full-scale powered SMV would be designed to be about 7.5 meters long and have a mass of about 1140 kg. The USAF 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.[74]

The Pentagon may use funding for the spaceplane program to enter into a cooperative program with NASA for the RLV technology development, possibly in conjunction with the Future X program.[75] In addition, Boeing's X-40A may be a potential vehicle design for the Advanced Technology Vehicle to be developed under the Future X program.

International Concepts

International public and private organizations are also designing RLVs to satisfy government and commercial launch needs. As with the U.S. commercial vehicles in the previous section, these vehicles are in various stages of development.

Defense Research Development Organization (India) – AVATAR

Vehicle: AVATAR

Developer: Defense Research Development Organization (India)

First launch: TBA

Number of stages: 1

Possible launch sites: TBA

Markets served: Satellite deployment.

Funding: Program has developmental funding of $5 million.

In May of 1998, India's Defense Research Development Organization (DRDO) announced the initial funding of the design of a small reusable spaceplane.[76] The Aerobic Vehicle for Advanced Trans-Atmospheric Research (AVATAR or Avtar) is planned to be the size of a jet fighter/bomber and would be capable of delivering 500 kg to 1000 kg to orbit.

The initial development budget is only $5 million, but project supporters claim that the vehicle can be built in ten years with total funding of under $2 billion. Designers admit, however, that international assistance would most likely be required for the project to reach its goal. In addition to the DRDO team working on the conceptual design, development of technology components is being undertaken by academic institutions in India as well.[77]

The AVATAR would take off horizontally using ramjet engines that burn air and hydrogen. Once at a cruising altitude, the vehicle would use scramjet propulsion to accelerate to Mach 7. During these cruising phases, an on-board system will collect air from which liquid oxygen will be separated. The liquid oxygen collected then would be used in the final flight phase, when the rocket engine burns the collected liquid oxygen and the carried hydrogen to attain orbit. Both the scramjet engine concept and the liquid oxygen collection process have already undergone successful tests at DRDO and at the Indian Institute of Science. DRDO has approved further testing of the liquid oxygen process and assigned a team to conduct a detailed review of the vehicle's design.

National Space Development Agency of Japan – HOPE-XA Spaceplane

The National Space Development Agency of Japan (NASDA) 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, NASDA initiated the H-2 Orbiting Plane Experiment (HOPE) program. The program has progressed through 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 has performed automated landing tests.[78] A HOPE-X prototype vehicle was under development in 1997 before the project structure was changed.

Vehicle: HOPE-XA

Developer: NASDA

First launch: 2001

Number of stages: 3

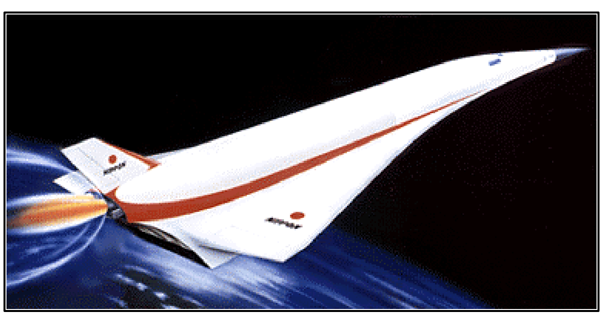
Possible launch sites: Tanegashima

Markets served: Delivery of supplies to International Space Station.

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

The current program calls for the HOPE-X prototype under development to be modified for repeated space operations. This HOPE-XA 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-XA will also be launched from the new, less-expensive H-2A vehicle, and is proposed for a 2001 first launch.[79]

The original HOPE spaceplane was designed not only to deliver and retrieve cargo from the International Space Station, but also to provide a testbed for technologies required to develop a fully reusable spaceplane. NASDA's Space Activities Commission is examining the number of flights required of the HOPE-XA to provide the data and technologies necessary to proceed with development of an SSTO spaceplane.[80]



National Aerospace Laboratory (Japan) – SSTO Spaceplane

Japan's long-term reusable launch vehicle goal is the construction of a single-stage-to-orbit (SSTO) spaceplane. The Japanese government modified the HOPE spaceplane program (see HOPE-XA entry) 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.

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.

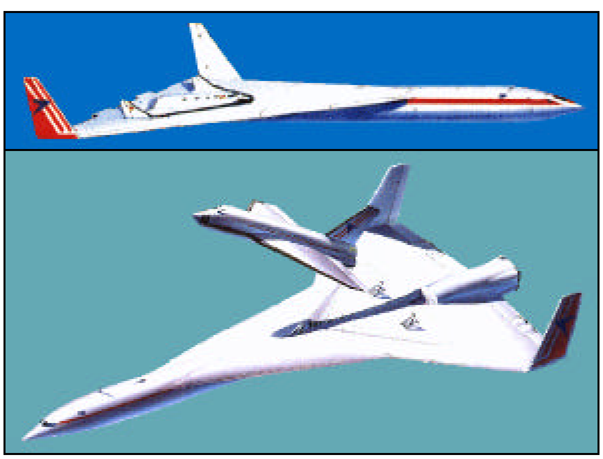
Funding: Program funded to an unknown level by the Japanese government.

The National Aerospace Laboratory concept calls for the development of a SSTO prototype rocket by 2010 and the final SSTO Spaceplane by 2020.[81] 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 studying advanced propulsion systems in support of the program. Development of the spaceplane is expected to cost $20 billion.[82] 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 50 meters in length, with a mass of about 52 metric tons.

The SSTO Spaceplane would use 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 at an altitude of 20 km, 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. [83]

Tetsuo Tanaka, senior engineer at NASDA, has stated development could begin before 2010 if funding becomes available after 2003 and if several flights of the HOPE-XA are undertaken. According to Tanaka, however, "propulsion technology breakthroughs and international cooperation would be necessary if Japan is ever to seriously consider spaceplane development."[84]



Bristol Spaceplanes Ltd. – Spacecab/Spacebus

Spacecab and Spacebus are similar concepts promoted by Bristol Spaceplanes Limited (BSL) of Bristol, England. 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

The Spacecab would be a prototype two-stage spaceplane. The first stage would consist of a

Vehicle: Spacecab (top)/Spacebus (bottom)	
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.	

supersonic aircraft similar to the Aerospatiale/British Aerospace-built 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.[85]

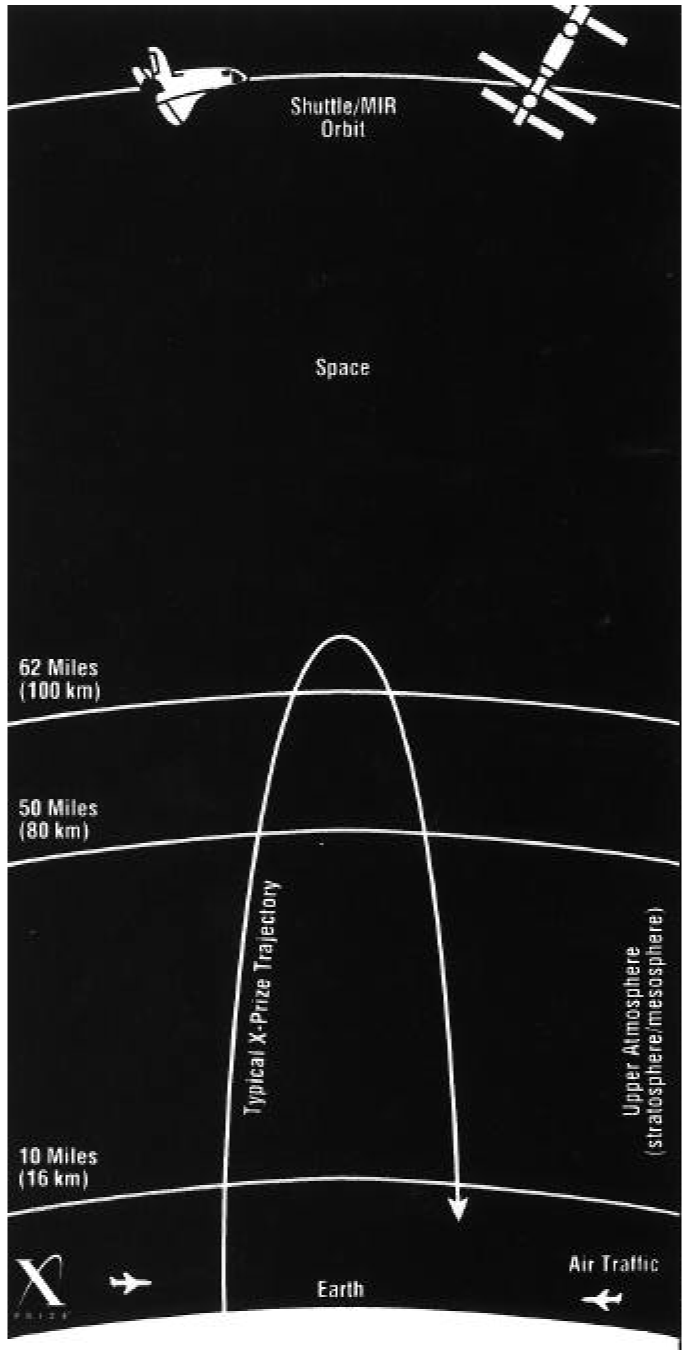
Spacebus is an enlarged version of the Spacecab. The Spacebus booster would have a length of approximately 88 meters and a mass of 130,000 kg, while the orbiter would be 34 meters long with a mass of 19,900 kg. The Spacebus booster would have greater power and accelerate to Mach 6 for orbiter separation. The orbiter would be capable of carrying 50 passengers.[86]

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.[87]

X PRIZE[SM] Competitors

The X PRIZE[SM]

In the spirit of the early 20th century aviation prizes, such as the Orteig prize that Charles Lindbergh won for crossing the Atlantic in 1927, the X PRIZE[SM] 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[SM] Foundation is offering a $10 million prize to the first entrant able to launch a vehicle capable of carrying three people to a 100-km sub-orbital 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[SM] is offered to help speed along development of space vehicle concepts that will reduce the cost of access to space and to allow human spaceflight to become routine.



Typical X PRIZE[SM] Trajectory

The X PRIZE[SM] competition currently has 15 entrants offering a variety of different RLV concepts. The commercial vehicles under development for the X PRIZE[SM] competition are generally uniquely designed for sub-orbital space tourism operations carrying about three to six passengers. These designs use many different takeoff, landing, and design concepts, but all plan to use existing technology to accomplish their goals.

The X PRIZE[SM] Foundation made significant strides during 1998. During the year, the Foundation signed up additional sponsors, including author Tom Clancy, pushing their prize funding to $7 million of the $10 million offering.[88] Two X PRIZE[SM] entrants, Paul Tyron and HMX, dropped out of the competition, while another, Dale Cooper Harris, registered as an entrant. In May, the X PRIZE[SM] Foundation announced a line of credit cards, the use of which enters individuals in a sweepstakes that would award the winner a trip into space. Also in May, the Foundation unveiled the X PRIZE^{SM} trophy, which was put on display at the National Air and Space Museum in Washington DC.

The table below provides a summary of the X PRIZE^{SM} vehicles.

Program	Developer	Vehicle Type
Ascender	David Ashford, Bristol Spaceplanes Limited	Spaceplane powered by two conventional jet engines and a liquid-fueled rocket engine; The vehicle will take off and land horizontally
Astroliner	Kelly Space and Technology	See the Astroliner entry for information
Cosmos Mariner	Dynamica Research	Spaceplane powered by two air-breathing engines and one rocket engine; The vehicle will launch and land horizontally
Gauchito	Pablo De Leon and Associates	Two-stage vehicle that will launch vertically; The first stage booster and the second stage passenger capsule return to Earth using parachutes
Green Arrow	Graham Dorrington	Cylinder-shaped rocket using liquid-fueled rocket engines; The vehicle will launch vertically and launch vertically using parachutes and air bags
Lucky Seven	Mickey Badgero	Cone-shaped vehicle powered by rocket engines; The vehicle will launch vertically and land using a parafoil
Mayflower (CAC-1)	Advent Launch Services	Cylinder-shaped glider powered by liquid-fueled rocket engines; The vehicle will launch vertically from water and land horizontally in water
PA-X2	Rick Fleeter, AeroAstro Inc.	Cylinder-shaped vehicle using a liquid-fueled engine; The vehicle will launch vertically and land horizontally using a steerable parafoil
Pathfinder	Pioneer Rocketplane	See the Pathfinder entry for information
Proteus	Burt Rutan, Scaled Composites	Two-stage vehicle consisting of the conventional turbo-fan powered Proteus aircraft and a rocket-powered second stage
The Space Tourist	John Bloomer, Discraft Corporation	Disc-shaped vehicle powered by air-breathing "blastwave-pulsejets;" The vehicle will take off and land horizontally
Thunderbird	Steven M. Bennett, Starchaser Foundation	Cylinder-shaped rocket using air-breathing engines and liquid fueled rocket engines; The vehicle will launch and land vertically
X Van	Pan Aero, Inc., Third Millennium Aerospace	Pan Aero has publicized two designs for the X Van; The entry may be a two-stage-to orbit system comprised of a booster stage and orbiter stage, or a single-stage system flying a sub-orbital trajectory
unnamed	William Good, Earth Space Transport System Corporation	No information on this entry has been released
unnamed	Dale Cooper Harris, Coopership Industries	Two-stage system taking off horizontally from water and using a turbofan-powered airship for the first-stage; The second-stage shuttle uses a solid-fuel rocket engine to reach a sub-orbital altitude and then employs a turbojet engine upon re-entry for a horizontal water landing

Several of the X PRIZE^{SM} entrants also took steps forward in developing their vehicles during 1998. The progress of Pioneer Rocketplane and Kelly Space and Technology is reported in the *Commercial Launch Programs* section. The X Van entry of Pan Aero underwent design modifications, and Bristol Spaceplanes Ltd. flew a remote-controlled one-fifth scale prototype of its Ascender design. Most visible, however, was Scaled Composites' September test flight of the Proteus aircraft, which will serve as the first stage for its X PRIZE^{SM} vehicle entry.[89]

Several of the competitors have commercial plans for their vehicles after the X PRIZE^{SM}. In addition to the already discussed plans of Pioneer Rocketplane and Kelly Space and Technology, Scaled Composites' Proteus aircraft is planned for use for missions such as atmospheric research, reconnaissance, microsatellite launch, and as a telecommunications platform over metropolitan areas.[90] The Mayflower and the Ascender are planned for continued use as commercial space tourism platforms. The X Van and the Cosmos Mariner are proposed for both satellite launch and space tourism missions.

Acronyms

ACRV – Assured Crew Return Vehicle
AFB – Air Force Base
AFRL – Air Force Research Laboratory
AFSPC – United States Air Force Space Command
ALFLEX – Automatic Landing Flight Experiment
AST – Associate Administrator for Commercial Space Transportation (FAA)
ATV – Atmospheric Test Vehicle (Roton); Advanced Technology Vehicle (NASA)
AVATAR –Aerobic Vehicle for Advanced Trans–Atmospheric Research
BSL – Bristol Spaceplanes Limited
CATS – Cheap Access to Space
CRV – Crew Return Vehicle
CTV – Crew Transfer Vehicle
DLR – Deutschen Zentrum für Luft– und Raumfahrt (German National Aerospace Research Center/German Space Agency)
DRDO – Defense Research Development Organization (India)
EELV – Evolved Expendable Launch Vehicle
ELV – Expendable Launch Vehicle
ESA – European Space Agency
EXD – Eclipse Experimental Demonstration
FAA – Federal Aviation Administration
GEO – Geosynchronous Orbit
GTO – Geosynchronous Transfer Orbit
HOPE – H-2 Orbiting Plane Experiment
HYFLEX – Hypersonic Flight Experiment
ICT – Integrated Concept Team
ISS – International Space Station
JSC – Johnson Space Center
KSC – Kennedy Space Center
KST – Kelly Space and Technology
LACE – Liquefied Air Cycle Engines
LEO – Low Earth Orbit
LLC – Limited Liability Corporation
LOX – Liquid Oxygen
MEO – Medium Earth Orbit
MSFC – Marshall Space Flight Center
NASA – National Aeronautics and Space Administration
NASDA – National Space Development Agency of Japan
NTS – Nevada Test Site
PTV – Propulsion Test Vehicle (Roton)
RFP – Request For Proposal
RLV – Reusable Launch Vehicle
SCS – Space Cruiser System
SMV – Space Maneuver Vehicle
SSPP – (RLV) System Safety Program Plan
SSTO – Single-Stage-to-Orbit
TBA –To Be Announced
TSTO – Two-Stage-to-Orbit
USAF – United States Air Force
X-vehicle – Experimental Vehicle

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Reusable Launch Vehicle Programs and Concepts

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
Commercial Programs													
Astroliner	2002	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; Upper stages under consideration include Thiokol's Star 71, and Pratt & Whitney Orbus 21	4700 kg to 300 km 28.5 deg. LEO 3950 kg to 300 km 86 deg. LEO 3400 kg to 1700 km 28.5 deg. LEO 2700 kg to 1700 km 86 deg. LEO 2072 kg to GTO	air-launched	horizontal landing	yes	no	Launch of LEO constellation satellites and GTO payloads	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
K-1	1999 or 2000	Kistler Aerospace Corporation	2	First stage: 3 GenCorp Aerojet AJ-26 kerosene/ LOX engines Second stage: 1 GenCorp Aeroject AJ-60 kerosene/ LOX engine	4200 kg to 370 km 37 deg. LEO 2350 kg to 370 km Polar 2050 kg to 1100 km 37 deg. LEO 450 kg to 1100 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	2000 or 2001	Pioneer Rocketplane	2	2 Pratt and Whitney F100 air-breathing engines, 1 RD-120 LOX/kerosene engine	2100 kg to 200 km Equatorial 1600 kg to 200 km Polar 1900 kg to 1000 km Equatorial 1450 kg to 1000 km Polar	horizontal takeoff	horizontal landing	no	yes	Launch of LEO constellation satellites	Scaled Composites, ARB Rockets Incorporated		Wallops Island, Vandenberg, Kodiak Island
Roton C-9	2000	Rotary Rocket Company	1	Rocketjet aerospike LOX/ jet fuel engine	3600 kg to 275 km 35 deg. LEO 2700 kg to 370 km 90 deg. LEO 3150 kg to 550 km 35 deg. LEO 2250 kg to 550 km 90 deg. LEO	vertical launch	vertical landing	no	no	Launch of LEO constellation satellites	Scaled Composites, Advanced Rotorcraft Technologies, Deskin Research Corp., Hypersonics Inc., Aerotherm Corp., Altus Associates, Luna Corp., Guidance Dynamics Corporation, Howard & Houston Engineering, Inc., LAPCAD, National Technical Systems		
SA-1	2001	Space Access LLC	2 or 3	Ejector LOX/hydrogen ramjets for each stage		horizontal takeoff	horizontal landing	no	no	Launch of medium-class LEO and GTO payloads	Kaiser Marquardt, undisclosed "major aerospace firms"		Homestead AFB
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 sub-orbital	horizontal takeoff	horizontal landing	yes	no	Sub-orbital space tourism; Sub-orbital microgravity and other experiments; Aerospace training	AeroAstro		Commercial airports capable of servicing business jets
VentureStar	2004	Lockheed Martin Skunk Works	1	7 RS-2200 linear aerospike engines	22,700 kg to LEO	vertical launch	horizontal landing	no		VentureStar launch of heavy-class LEO payloads			
United States Government Programs													
X-33	2000	Lockheed Martin Skunk Works	1	2 J-2S linear aerospike engines	Mach 13.8 at 91 km	vertical launch	horizontal landing	no	yes	Testbed for RLV technologies and operations	LM Space Operations, LM Manned Space Systems, LM Astronautics, LM Engineering and Sciences, Sanders, Rocketdyne, Rohr, AlliedSignal, Alliant Techsystems, Sverdrup		
X-34	2000	Orbital Sciences Corporation	1	One kerosene/LOX Fastrac engine One Russian-built NK-39 engine	Mach 8 at 76 km 181kg payload allocation	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			
X-38/Crew Return Vehicle	2000	Scaled Composites	TBA	X-38: none CRV: Expendable Deorbit Propulsion Stage (DPS)	CRV: Emergency International Space Station crew return capability	on-board Space Shuttle	horizontal landing	no	yes	Prototype for International Space Station crew return operations	Pioneer Aerospcace, SSE Inc.		
Military Spaceplane	TBA	Boeing, Lockheed Martin	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			
International Concepts													
AVATAR (India)	TBA	Defense Research Development Organization	1	Powered by turbofan ramjet engines, airbreathing propulsion engines for atmospheric flight	1/2 metric ton to one metric ton to LEO	vertical launch	horizontal landing	no	yes	Launch of LEO payloads; Security services: intelligence, surveillance, and reconnaissance			
HOPE-XA Spaceplane (Japan)	2001	National Space Development Agency of Japan	3	Thrusters utilizing nitrogen tetroxide and either monomethelhydrazine or hydrazine	3000 kg to space station orbit 1000kg to 200km 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
SSTO Spaceplane (Japan)	2010	National Aerospace Laboratory	1	Multiple liquid propellant engines Airbreathing engines for atmospheric flight	10,000 kg to 500 km 28.5 deg. LEO	horizontal takeoff	horizontal landing	no	yes	Launch and recovery of LEO payloads			
Spacecab/ Spacebus (Great Britain)	2010	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 750 kg to LEO	horizontal takeoff	horizontal landing	no	no	Orbital space tourism; Launch of small-class LEO payloads; ISS crew transfer; Repair of satellites in LEO			