REUSABLE LAUNCH VEHICLES & SPACEPORTS: PROGRAMS & CONCEPTS FOR 2001

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Associate Administrator for Commercial Space Transportation
Federal Aviation Administration

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Introduction

The Publication

This report, *Reusable Launch Vehicles and Spaceports: Programs and Concepts for 2001*, provides technical and business information on U.S. commercial and government reusable launch vehicles (RLVs) and spaceports. The report describes operational vehicles and spaceports as well as efforts currently in development or proposal stages.

The Federal Aviation Administration (FAA) Associate Administrator for Commercial Space Transportation (AST) first published this report in 1998. Now in its fourth edition, this publication is similar to its predecessors but contains some important additions and changes. Each individual RLV entry has been updated with the most recent publicly available information on the RLV's financial, technical, testing, and manufacturing situation. Each spaceport entry has been updated with respect to financing and infrastructure investment and upgrades. Other significant changes include a more narrow focus on U.S. RLV concepts and programs; except for those competing for the X PRIZE®, international RLV concepts under consideration for development are not discussed in this report. Finally, the section on U.S. government RLV programs only focuses on concepts that are intended for space *launch* opposed to space flight. The resulting report is a comprehensive overview of the RLV industry in the United States.

RLV Industry Background

RLVs have become attractive alternatives for access to space for several reasons. With the exception of the United States' Space Shuttle, world access to space is made possible by expendable launch vehicles (ELVs), or rockets that can only be used once. As a new vehicle is needed for each launch, the customer who purchases a launch must pay the cost to build an entire vehicle. In contrast, an RLV has the capacity not only to launch but also to return to Earth to be used again. Because the cost of construction of an RLV could be amortized over multiple launches, RLVs may potentially reduce the cost of access to space for government and commercial users. In addition, the return nature of RLVs facilitates human trips to and from space. Although many national governments and companies have explored the development of RLVs, the Space Shuttle—first flown in 1981—remains the first and only currently operational, partially reusable launch vehicle (the orbiter and solid rocket boosters are refurbished and reused, but the external tank is irrecoverable).

Starting in the 1990s, however, both the public and private sectors intensified RLV design and development efforts. On the commercial side, RLV design and development activity increased in response to strong growth in projected launch demand during the 1990s fueled primarily by non-geostationary orbit (NGSO) satellite telecommunications constellations. These NGSO constellations required large numbers of satellites for initial deployment as well as many replacements and follow-on satellites. In 1998, FAA/AST projected that 1,063 NGSO satellites would be deployed between 2000 and 2010.

Unfortunately, the operators and proponents of NGSO systems have suffered substantial setbacks. In particular, the pioneering Iridium NGSO mobile telephony system, which deployed 88 spacecraft on 20 launches, failed to attract enough subscribers to service its debt and was compelled to file for bankruptcy protection. The ICO system, which had not yet been deployed, soon followed suit. As a result, future NGSO satellite constellations, as well as the replacements and follow-ons of existing NGSO constellations, face increased market skepticism as and appear less likely to be funded and launched. FAA/AST's year 2000 NGSO forecast reflected these reduced expectations and included only 552 NGSO satellite deployments between 2000 and 2010.

The bankruptcies, along with the associated reduced launch projections, have made it increasingly difficult for commercial RLV companies to obtain capital from private investors to complete their vehicle development. The year 2000 was particularly difficult for U.S. RLV companies, as many vehicle development programs were stalled or delayed due to lack of funds.

The government also exhibited increased RLV design and development activity starting in the mid-1990s. For many reasons, the Space Shuttle had proven and remained extremely expensive to operate, and the Shuttle's aging orbiters required expensive upgrades. The National Aeronautics and Space Administration (NASA) thus began to consider next-generation RLVs that would be more efficient alternatives to meet its space transportation requirements. Consequently, NASA embarked on an ambitious series of experimental vehicle, or X-vehicle, programs.

The centerpiece of these programs was NASA's X-33, a sub-orbital vehicle that would demonstrate technology for a reusable, single-stage-to-orbit (SSTO) launch vehicle. Lockheed Martin, the prime contractor for X-33 planned to develop a commercial RLV called VentureStar™ that would use X-33 technology. Originally, 15 flights from Edwards Air Force Base (AFB) in California to landing sites in Utah and Montana were planned to be completed by the end of 1999, and the demonstrator vehicle was to have flown at Mach 15. However, technical problems related to the manufacture of the composite propellant tanks pushed back the flights and reduced the velocity goals. The first flight of the X-33 vehicle has been delayed until 2003.

RLV Industry Outlook

While the year 2000 was a challenge for the RLV industry, the industry is proving to be resilient and adaptable. Several commercial RLV companies remain committed to the goal of developing and operating their vehicles. These companies are aggressively pursuing private investment, and many have revised their business plans to include a much higher percentage of government payloads. Many are focusing on re-supplying the International Space Station (ISS). NASA has not yet selected any contractors for re-supply.

NASA also is adapting to current realities. The space agency is incorporating lessons learned from the X-33 program into its Second Generation Reusable Launch Vehicle Systems Engineering Risk Reduction program. NASA's Second Generation RLV program received support from Congress and the President when the Space Launch Initiative (SLI) was passed into law in Fall 2000. SLI is a new budget initiative that commits $4.5 billion over five years to NASA to pursue the Second Generation RLV program. Rather than focusing on a specific vehicle concept, the program is designed to substantially reduce the technical, programmatic, and business risks associated with developing a safe, reliable, and affordable second generation RLV. NASA intends to sustain commercial competition through 2005 and to invest in high-priority risk reduction work. The desired payoff of these investments is to enable the initiation of full-scale development of commercially competitive, privately owned and operated RLVs by 2005, and operations by 2010.

2000 Developments

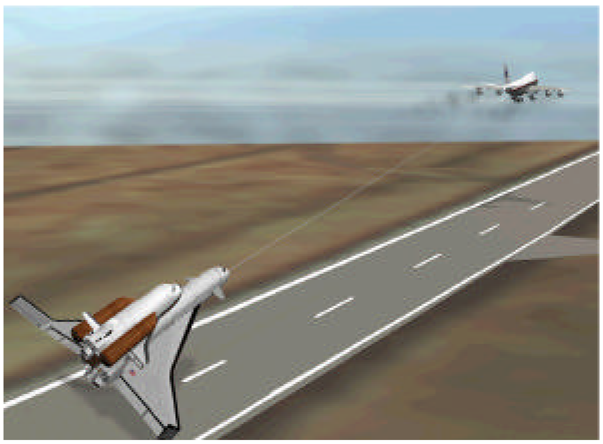
The following chronology summarizes key events related to commercial and U.S. government RLVs that took place in 2000:

- *January 19* - A Red Team chaired by NASA and Lockheed Martin began the first of two sessions to review the health of the X-33/VentureStar program. The second session took place in February.
- *February 9* - The Red Team, which previously met in January, concluded that the X-33 program was on track.
- *February 11* – Space Shuttle *Endeavor* (STS-99) was successfully launched, carrying the Shuttle Radar Topography Mission instrument. The mission mapped an estimated one trillion points on the Earth's surface.
- *April 11* – NASA announced its decision to redesign and rebuild the X-33 hydrogen fuel tanks with aluminum. The original design used a lightweight, composite material that could not withstand pressurization tests. The announcement was made to the Subcommittee on Space and Aeronautics, Committee on Science, U.S. House of Representatives.
- *April 13* – Kistler Aerospace signed a Memorandum of Agreement with Space Operations International to provide launch accommodations for small payloads on the K-1 vehicle.
- *April 24* – Rotary Rocket Company signed a Memorandum of Agreement with Space Operations International to provide launch accommodations for secondary payloads on the Roton vehicle.
- *May 12* – Final hot fire tests on a single X-33 aerospike engine were successfully conducted, completing the first series of engine tests.
- *May 19* - The Space Shuttle *Atlantis* (STS-101) lifted off with the new Multifunction Electronic Display Subsystem (MEDS) installed in the cockpit. MEDS will be installed on the remaining orbiters by 2003, and will not be fully utilized until new computers are installed that same year.
- *June 20* – Kelly Space and Technology won a NASA contract for risk reduction studies and analysis of a second generation RLV program.
- *June 20* – SPACE ACCESS® won a NASA contract to develop aerospace worthiness standards.
- *June 26* – Gary Hudson resigned as CEO of Rotary Rocket Company and was replaced by Rotary's CFO, Helena Hardman.
- *June 30* – Pioneer Rocketplane received a $200,000 grant from the State of California to develop a detailed structural concept for a low-cost upper stage.
- *July 17* – The X PRIZE® foundation approved the application of the da Vinci Project as a new entrant to the $10 million X PRIZE® competition.
- *July 6* – Starchaser Industries, an X PRIZE® competitor, successfully launched a two-stage rocket from Morecambe Bay, United Kingdom, to test a launch escape system and avionics for its Thunderbird vehicle.
- *July 20* – The X-34 program began a series of ground tests on the A-1A unpowered test vehicle at Edwards AFB, California. These tests were designed to investigate roll-out characteristics, guidance and navigation systems, and nose gear mechanisms.

- *August 10* – The X-33 liquid hydrogen tank failure report was released. The report concluded that the design of the tank was the primary reason for the failure (fracturing), and that manufacturing flaws were only a secondary contributor.
- *August 23* – Kitten, a vehicle being developed by the Cerulean Freight Forwarding Company of Oroville, Washington, became the 19th entrant to the X PRIZE® competition.
- *August 25* – Kistler Aerospace was awarded a contract by NASA to conduct a study for alternate access to the ISS.
- *September 13* – Pioneer Rocketplane signed a Memorandum of Understanding with the Oklahoma Space Industry Development Authority for $300 million in revenue bond financing in exchange for a commitment to conduct launches from the proposed Oklahoma Spaceport.
- *September 29* – NASA and Lockheed Martin agreed to a new plan for the X-33. The plan included a revised payment schedule for only one more promised payment, the use of aluminum hydrogen tanks as opposed to the problematic composite tanks, and a target launch year of 2003. Lockheed Martin will be able to compete for additional funds from the Second Generation RLV Program.
- *October 11* – NASA launched the 100th mission of the Space Shuttle, with *Discovery* (STS-92) sending up hardware for installation on the ISS.
- *October 27* – President Clinton signed into law NASA's appropriations bill for fiscal year 2001 which included $290 million for the Space Launch Initiative (SLI).
- *December* – Preparations for a 2001 test on a tandem X-33 aerospike engine configuration began at NASA's Stennis Space Center, Mississippi. Fourteen test firings of a single aerospike engine have already been successfully completed at Stennis.

United States Commercial Programs

The private sector is developing a variety of RLV concepts with plans to perform both payload launch and human passenger/crew missions. The vehicles described in this section are in various stages of development.



Vehicle: 2nd Generation RLV System	
Developer: Kelly Space and Technology	
First launch: post-2006	
Number of stages: 3-4 (including towing aircraft)	
Payload performance: 4,700 kg to 300 km/28.5 deg. LEO	
Possible launch sites: East/West/Gulf Coast locations, eventually mid-continent	
Markets served: Humans and cargoes to all conventional orbits	

Second Generation Reusable Launch Vehicle – Kelly Space and Technology

Slowed development of the NGSO satellite market has prompted a change in Kelly Space and Technology efforts to develop space transportation capabilities. Last year, Kelly planned to design and develop the Astroliner vehicle for launch in 2002. The company is now focused on development of "Second Generation" RLV capabilities that will serve sub-orbital, NGSO, geostationary orbit and ISS customers.[1]

Kelly's piloted Second Generation RLV system will be based on its patented horizontal takeoff and landing, tow-launch technique and is designed to carry humans and cargoes to and from destinations off the Earth. The two-stage-to-orbit (TSTO) system will be towed to its various airborne launch sites using a modified Boeing 747 aircraft. The RLV's on-board turbine engines will supplement the thrust of the tow aircraft during the initial ascent. The RLV system will be released at the launch site and, using its rocket engines, ascend to stage separation. The second stage system for the specific mission will proceed to orbit. The first stage will return to its planned landing site, using its turbine engines again for powered landing on conventional runways.

Kelly's RLV system includes a number of different upper stage vehicles, including cargo-only delivery/return vehicles, and a seven person Crew Transfer Vehicle (CTV). The system is designed to serve all current and future customers anticipated through 2030, including both government and private citizen space travelers. The system design will readily accommodate the use of customer-supplied orbit-transfer stages in conjunction with their satellites or other cargoes. The CTV incorporates its own propulsion system for orbit-deorbit and orbital maneuvering needs.

Kelly has received a U.S. patent for its tow-launch concept. Kelly's tow-launch technique will facilitate significant reductions in expensive ground facilities infrastructure, will achieve system operating safety and reliability that approaches commercial airline operations, and will enable delivery of heavier payloads than can be achieved with other air-dropped system concepts.

Under a cooperative program with NASA's Dryden Flight Research Center and the Air Force Flight Test Center at Edwards AFB, Kelly's tow-to-launch concept has been successfully flight demonstrated. Using a modified QF-106 and a C-141A tow aircraft, Kelly successfully conducted six flight tests to demonstrate the RLV tow-launch technique in late 1997 and early 1998.

Since mid-1998, Kelly has been performing Second Generation RLV Architecture and System Engineering and Risk Reduction Studies in support of the Government's Integrated Space Transportation Plan. In August 2000, Kelly won a new contract from NASA for Risk Reduction Studies and Analysis of a Second Generation RLV System.[2]

K-1 – Kistler Aerospace Corporation

Kistler Aerospace Corporation is developing the K-1 RLV for commercial launches of low-earth orbit (LEO) payloads. The K-1 design was developed in 1995 and 1996 as a TSTO vehicle that will have a payload capacity of 4,500 kilograms to a standard LEO and will offer launch prices of about $17 million per launch.[3] Kistler has completed a conceptual design for an Active Dispenser that will deploy payloads to medium-earth orbit, geosynchronous transfer orbit (GTO), and interplanetary orbits. The Active Dispenser will expand the K-1's capability beyond LEO (approximately 1,570 kilograms to GTO) at a launch price of about $25 million.[4] The K-1 is also capable of providing cargo resupply and return services to and from the ISS. In August 2000, Kistler was awarded a three-month study contract from NASA Marshall Space Flight Center for assessing the K-1 as a potential vehicle to provide alternate access to the ISS.[5]

Vehicle: K-1

Developer: Kistler Aerospace Corp.

First launch: To be determined

Number of stages: 2

Payload performance: 4,000 kg to 400 km/45 deg. LEO

Planned launch sites: Woomera, Australia; Nevada Test Site, NM

Markets served: Deployment of LEO payloads, GTO payloads (with Active Dispenser), ISS resupply, and cargo return missions

The K-1 is also capable of launching multiple small payloads as secondary payloads or on dedicated missions. In April 2000, Kistler announced it had signed a Memorandum of Agreement with Space Operations International, a new company jointly formed by Ball Aerospace and Technologies and the

Universities Space Research Association. Under the agreement, Kistler will offer Space Operations International excess space on K-1 missions for secondary payloads.[6] Kistler and Astrium Ltd. of Europe are exploring development of reusable payload dispensers for multiple small payloads. Astrium's multiple payload adapter system design for the K-1 is based on a similar system developed for Ariane 4 and 5.[7]

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 with a mobile transporter. The K-1 vehicle will measure about 36.9 meters high, with a launch mass of 382,300 kilograms.[8]

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 AJ26 series engines. These engines include the core of the NK-33 engines originally built by the Russians in the 1960s for their moon mission program. After launch, the Launch Assist Platform separates from the second stage and restarts its center engine to fly a return trajectory to a landing area near the launch site. The Launch Assist Platform deploys parachutes and descends to the landing area where air bags are deployed to cushion its landing.

The second stage, or Orbital Vehicle, continues into LEO where it releases its payload. The Orbital Vehicle is powered by a single Aerojet AJ26-60 engine (derived from the Russian NK-43 engine). Following payload separation, the Orbital Vehicle continues on orbit for about 24 hours, after which a LOX/ethanol orbital maneuvering system performs a de-orbit burn. After atmospheric re-entry, the Orbital Vehicle flies a guided re-entry path to a 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 have been achieved. The K-1 vehicle is 75 percent complete. Northrop Grumman Corporation has been contracted to provide the vehicle structure and has completed 21 of the 23 major structural panels for the K-1,[9] while Aerojet has undertaken test firings of the modified AJ26 engines.[10] Lockheed Martin has completed the LOX tanks. Irvin Aerospace has conducted a series of drop tests on the parachute and airbag systems, and final vehicle assembly commenced in May 1998.

Kistler is planning to operate the K-1 vehicle from two launch sites, one in Woomera, Australia, and one at the proposed Nevada Test Site. Kistler received authorization from the Australian government to begin construction of launch facilities at Spaceport Woomera in April 1998 and held a groundbreaking ceremony at the site in June 1998. The launch pad designs are complete, and Kistler will conduct its initial flight tests and commercial operations from Woomera. In October 1998, Kistler finalized a deal with the Nevada Test Site Development Corporation to permit Kistler to occupy a segment of the Nevada Test Site for its launch operations.[11] An environmental assessment for Kistler operations at the Nevada Test Site is being finalized and is an initial step in the process of gaining an FAA license for launch and recovery of the K-1 at the Nevada site.

Pathfinder – Pioneer Rocketplane

Vehicle: Pathfinder

Developer: Pioneer Rocketplane

First launch: To be determined

Number of stages: 2

Payload performance: 2,100 kg to equatorial LEO

Possible launch sites: Oklahoma Spaceport; Vandenberg AFB, CA; Cape Canaveral, FL

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

The Pathfinder tracks its heritage to a military spaceplane concept.[12] The "Black Horse" spaceplane was promoted within the U.S. Air Force in the early 1990s. Pioneer Rocketplane developed a derivative design that it called "Pathfinder" and proposed a precursor to it as a potential design for NASA's X-34 vehicle (discussed in the United States Government Programs section).

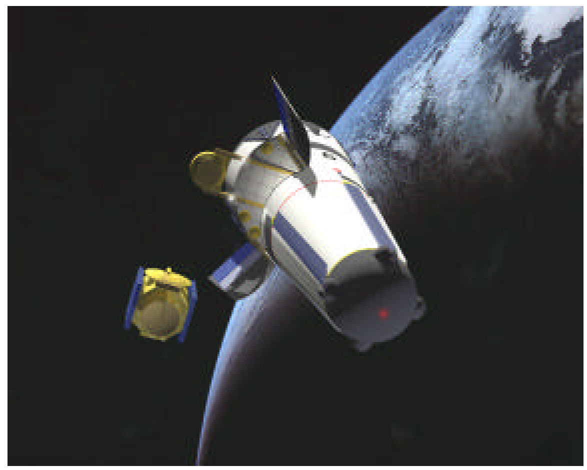
Although the Pioneer Rocketplane design was not selected for the X-34, the company elected to continue Pathfinder development. In June 1997, Pioneer Rocketplane was awarded one of four $2 million NASA Low Cost Boost Technology Program contracts to develop detailed preliminary designs and conduct wind-tunnel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

Pathfinder is a spaceplane to be operated by a crew of two and will be powered by both airbreathing jet engines and LOX/kerosene rocket engines. The 23-meter long vehicle will take off horizontally using turbofan jet engines. When it reaches an altitude of six kilometers, the Pathfinder will meet a tanker aircraft that will transfer about 59,000 kilograms of LOX to the Pathfinder's LOX tanks in a method identical to air-to-air refueling. After disconnecting from the tanker, the spaceplane will ignite its RD-120 rocket engine and climb to an altitude of 112 kilometers at a speed of about 4 kilometers per second. Once out of the atmosphere, the Pathfinder will be able to open its cargo bay doors and release its payload with a conventional rocket upper stage. The payload will then be carried into orbit as the spaceplane re-enters the atmosphere. After deceleration to subsonic speeds, the Pathfinder will re-start its jet engines and land horizontally.[13] The Pathfinder's maximum payload capacity to a space station orbit will be 2,300 kilograms.

The Pathfinder vehicle will use existing technology and components. The propulsion system will use proven jet and rocket engines (two GE F404 turbofan engines and one kerosene/oxygen-burning RD-120 rocket engine), and the avionics systems will be derived from existing military aircraft. In September 1998, Pioneer Rocketplane announced that it had completed a system design review and concluded that all components and systems fit together properly. In May 1999, Pioneer was also awarded a $40,000 grant by the State of California to conduct a study on the possibility for Pathfinder to launch from the California coast. Pioneer received an additional $200,000 California Space Grant award in June 2000 to develop a structural concept and plan for manufacturing of a low-cost upper stage.[14]

On September 13, 2000, Pioneer signed a MOU with the Oklahoma Space Industry Development Authority. Under the terms of the MOU, the Oklahoma Space Industry Development Authority agreed to provide up to $300 million in revenue bond financing to help finance the development of the Pathfinder launch vehicle. In exchange for this financial assistance, Pioneer agreed to conduct launch operations from the proposed Oklahoma Spaceport at the former Clinton-Sherman AFB in Washita County, Oklahoma. Until such time as the FAA authorizes over-land launch corridors, Pioneer plans to base its vehicles at the Oklahoma Spaceport and ferry-fly to approved launch sites on the East or West coasts.[15]

Roton – Rotary Rocket Company



Vehicle: Roton
Developer: Rotary Rocket Company
First launch: To be determined
Number of stages: 1
Payload performance: 3,600 kg to 275 km/35 deg. LEO
Possible launch sites: To be announced
Markets served: Deployment of LEO satellites and crew transfer to and from space stations

The Rotary Rocket Company began development of the Roton launch vehicle in 1996. However, due to the difficulty of raising additional funding for its vehicle development, estimated at $60-80 million, Rotary Rocket stopped engineering and development work in the summer of 2000 and Gary Hudson resigned the post of CEO at Rotary. The company has now suspended all activities, including fund raising, and has put the organization on indefinite hold.[16]

The Roton was designed to provide launches of satellites to LEO and also to provide crew transfer to and from space stations. The SSTO Roton vehicle was designed to takeoff vertically like a conventional rocket and land vertically like a helicopter. The 19.5-meter high vehicle was to be powered by a cluster of several engines derived from the Fastrac engine developed by NASA.[17] The cargo compartment was positioned in the middle of the vehicle between the LOX tank (in the nose) and the kerosene tank (above the engine). Following ascension to LEO, the Roton was to deploy its payload and perform a de-orbit burn. The vehicle was designed to remain on-orbit for up to 72 hours.

The Roton was cone-shaped and had rotor blades that folded flat against the exterior. The vehicle used the rotor blades to control the vehicle descent after atmospheric re-entry. Each blade was powered by small hydrogen peroxide/methanol rocket motors on the blade tips that power the rotor.

The Roton planned to touch down vertically under the control of its two-person crew. The vehicle was designed to be serviced by a small team of ground personnel, and Rotary Rocket targeted turnaround times between flights of 24 hours or less.[18] The Roton also was designed to be able to return to Earth with the cargo bay fully loaded.

Rotary Rocket Company developed and tested many of its systems throughout 1998, including the rotor blade-tip engines and the rotor assembly. In addition, the company began construction of its manufacturing and flight operations facility in June 1998 at the Mojave Civilian Test Flight Center in California and completed the construction in January 1999.[19]

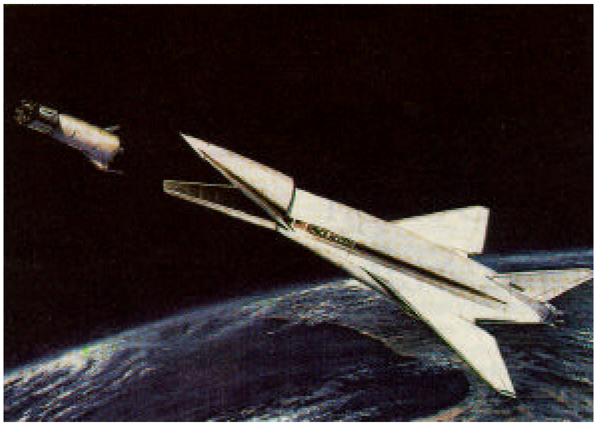
During 1998, Rotary Rocket also tested some of the systems for the proprietary RocketJet engine. This included several successful test firings of a LOX cooled combustion chamber with a thrust rating of approximately 2,700 kilograms. LOX cooling in a rocket engine allows for the use of an expander engine cycle with a LOX/kerosene fuel combination and many of the associated benefits. The RocketJet engine, a large centrifugal pumping engine design, was originally intended as the powerplant for the Roton vehicle; however, in June 1999 the company elected to proceed with development of the Fastrac variant using several of its achievements in engine design. According to Roton, this decision was made in order to "permit the Roton development program to be concluded more rapidly and with less technical risk."[20]

In 1999, construction of the Roton Atmospheric Test Vehicle (ATV) was completed and flight testing began. The ATV was a full-scale prototype vehicle without the main propulsion system and was designed to perform approach and landing tests. From July through October 1999, the ATV completed three test flights demonstrating the vehicle control characteristics needed for the Roton landing profile, including hovering and low altitude forward movement. With the majority of the desired engineering data collected, the company elected to cancel its final flight test and retire the vehicle early.

SA-1 – SPACE ACCESS®, LLC

SPACE ACCESS®, LLC, is developing the SA-1, an unmanned 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.

The entire SA-1 launch system is designed to be compliant with commercial aerospace worthiness standards, the equivalent of airworthiness standards for transport aircraft imposed by the FAA. The propulsion system for the system's first stage, the "aerospacecraft," is based on a proprietary modification by SPACE ACCESS® to the ramjet engine design that has been in operation since the early 1960s. The modification to the engines allows the ramjets to operate at both subsonic and supersonic speeds (ramjets normally only operate above Mach 2).[21] One of the company's subcontractors, Kaiser Marquardt, has tested elements of the propulsion system,[22] and SPACE ACCESS® has worked with the Air Force Research Laboratory since September 1995 under a Cooperative Research and Development Agreement to review the SA-1 aeromechanics and the "ejector" ramjet propulsion system. As of March 1998, SPACE ACCESS® had wind-tunnel tested the ejector ramjet engine at all of the altitudes and speeds of the SA-1's planned flight profile.[23]



Vehicle: SA-1

Developer: SPACE ACCESS®, LLC

First launch: 2007

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

Payload performance: 15,000 kg to LEO

Possible launch sites: Gulf Coast Regional Spaceport (Brazoria County, TX); Sarita Spaceport (Kenedy County, TX); Homestead Air Reserve Base, and Kennedy Space Center/Cape Canaveral Air Force Station, FL

Markets served: Launch of LEO and GTO payloads

The SA-1 vehicle will take off horizontally from a conventional runway, using a mixture of air and liquid hydrogen to power its ejector ramjet engines. As the aerospacecraft climbs and accelerates and reaches the limits of the atmosphere, it will gradually transition from ramjets to liquid rocket propulsion in order to reach its final altitude and speed of over 100 kilometers and Mach 9. The aerospacecraft will then deploy an upper stage with its satellite payload and return to land on a conventional runway. The SA-1 will carry a single, rocket-powered upper stage for LEO missions and two upper stages for GTO. After deploying the satellite payload, the upper stage will de-orbit and return to land horizontally on the same runway.[24]

The SA-1 vehicle will be able to launch payloads of over 5,200 kilograms to GTO. Although SPACE ACCESS® intends to pursue deployment of commercial geostationary satellites as its primary market, the SA-1 will also have a capability of deploying well over 15,000 kilograms to LEO as well. The SA-1's significant payload capability and reliability, derived from being designed in compliance with rigorous transport aircraft-based standards, will also make the SA-1 well-suited for conducting resupply missions to the ISS.[25]

In 1998, while working with NASA on a Space Transportation Architecture Study program contract, SPACE ACCESS® began to study the concept of developing a crewed version of the second stage, which would give the SA-1 the capability to provide human access to space. In 2000, NASA awarded SPACE ACCESS® a contract to develop Commercial Aerospace Worthiness Standards to be used by commercial RLV companies to obtain approval from the FAA to carry passengers for hire on commercial RLVs.[26]

In cooperation with the State of California, SPACE ACCESS® is now conducting tests of its proprietary integral hot structure which is based on the use of FAA-certified structural materials. SPACE ACCESS® currently plans to expand its test program over the next several years to include avionics and full-scale propulsion hardware as well.[27]

Space Cruiser System – Vela Technology Development

Vehicle: Space Cruiser System

Developer: Vela Technology Development, AeroAstro LLC

First launch: post-2003

Number of stages: 2

Payload performance: 8 humans to 100 km

Possible launch sites: Commercial airports

Markets served: Sub-orbital space tourism flights

The Space Cruiser System vehicle is marketed for space tourism flights by Space Adventures of Arlington, Virginia, which acquired Seattle-based Zegrahm Space Voyages in November 1999. The Space Cruiser vehicle is being designed and developed by Virginia-based Vela Technology Development, Incorporated, to carry six passengers and two crew members on a sub-orbital flight reaching an altitude of just over 100 kilometers.[28]

The Space Cruiser has a two-stage, horizontal-takeoff-and-landing design that employs both airbreathing and rocket engines. The first stage booster, or Sky Lifter, will be piloted by a two-member crew and will be powered by two JT8D/F100-class jet engines. The Sky Lifter is designed as a conventional jet aircraft with a 30-meter delta wing and with a dry mass of approximately 10,000 kilograms. The Space Cruiser second stage spaceplane will be carried underneath the Sky Lifter. The Space Cruiser will measure 18.3 meters from nose to tail and will weight about 11,800 kilograms with fuel and passengers. The two stages will climb together to about 15 kilometers where the Space Cruiser, carrying two crewmembers and six passengers, will separate and climb to 100 kilometers 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 activate two JT15D-class turbo-jet engines for landing.[29]

All preliminary testing has been successfully completed and Vela Technology is awaiting funding to proceed to the next phase of the development and construction. As financing could not be secured in 2000, a test flight is not expected to occur before 2003. Vela began considering a new, single-stage design for its vehicle that would use an airbreathing take-off and return.[30] Vela Technology Development and Space Adventures have received over 60 requests for reservations since they started marketing operations in October 1997 and are planning a first voyage two years after the first test flight.

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 Space Cruiser System.[31]

VentureStar™ – Lockheed Martin Corporation

Vehicle: VentureStar™

Developer: VentureStar LLC, Lockheed Martin

First launch: To be determined

Number of stages: 1

Payload performance: 22,700 kg to LEO

Possible launch sites: Multiple states are bidding to have a VentureStar launch site

Markets served: Launch of heavy-class LEO and GTO payloads and government satellites

VentureStar™ is Lockheed Martin's potential commercial follow-on to the X-33 vehicle the company is developing for NASA's RLV program. Development of a VentureStar™ vehicle will only be pursued at the conclusion of the X-33 program and will be contingent on the X-33 performance.[32]

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. Although original plans for the VentureStar™ called for an internal payload bay, the design was modified during 1999 to shift to an external payload bay.[33]

Lockheed Martin plans to target the commercial and government satellite launch markets. The company hopes to operate the vehicle at a flight rate of at least 40 launches per year, leading to launch costs of approximately $2,200 per kilogram. 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.[34]

Lockheed Martin plans to lease spaceport facilities for VentureStar™ operations. In July 1998, Lockheed Martin provided its spaceport requirements for the VentureStar™ to interested parties. Fifteen states responded to the requirements. A decision will likely not be made until development of the VentureStar™ vehicle begins.

United States Government Programs

There are currently four active RLV programs funded by the federal government: the Space Shuttle, the X-33, the X-34, and the Second Generation RLV program. The Space Shuttle has been operational since April 1981. The X-33, a one-half scale prototype being developed by Lockheed Martin for NASA, could have its first flight test in 2003. Orbital Sciences Corporation, the prime contractor for the X-34, is hoping this new RLV technology demonstrator will fly in less than two years. NASA is also funding the development of other X vehicles, including the X-37, X-38, and the X-43. These other X vehicles are not included in this report because they are not by nature space launch vehicles, but rather space flight vehicles.

NASA has also begun the Second Generation RLV program, a five-year, $4.5-billion budget initiative to support the development of next-generation RLVs. The goal of the Second Generation RLV program is to substantially reduce the technical, programmatic, and business risks associated with developing a safe, reliable, and affordable second generation RLVs.

Space Shuttle

NASA's Space Shuttle is the world's first operational RLV and has been used as the only mode of human space transportation in the United States since 1981. Although the Space Shuttles have launched several commercial and military satellite payloads during their initial years of service, commercial payloads were effectively banned from Shuttle manifests since the explosion of the *Challenger* in 1986. The Space Shuttle is now fully engaged in the construction of the ISS, will remain so until mid-2006, and will be used for logistics and research at least until 2012. NASA successfully completed its 100th Space Shuttle launch on October 11, 2000.

The Space Shuttle consists of a reusable delta-wing vehicle called an orbiter (there are four in the fleet and each has a lifetime of 100 flights); two solid-propellant rocket boosters, which are recovered and reused a maximum of 25 times each; and an expendable external tank containing liquid propellants for the orbiter's three main engines. The Space Shuttle carries astronauts to orbit to perform a wide variety of activities such as payload deployment and recovery, research in pressurized modules and unpressurized pallets in the cargo bay, repair of on-orbit assets, and ISS support.[35]

Vehicle: Space Shuttle

Developer: NASA, Rockwell International, Lockheed Martin, Thiokol. Operated by United Space Alliance for NASA

First launch: April 12, 1981

Number of stages: 2

Payload performance: 24,950 kg to 204 km/28 deg. LEO

Launch site: Kennedy Space Center, FL

Markets served: Heavy LEO payloads and human spaceflight

In October 1996, United Space Alliance, 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. In October 1999, United Space Alliance acquired USBI Co., gaining responsibility for the assembly, test, and refurbishment of the Space Shuttle's solid rocket boosters.[36] The move to a private contractor may allow for a reduction in program costs through elimination of program redundancies and the potential enhancement of Space Shuttle safety, reliability, and capability.[37]

Current plans call for the Space Shuttle fleet to remain in service until at least 2012.[38] In order to continue operations, a two-phased program to develop upgrades for the fleet is in place. Phase One upgrades are designed to enhance safety or vehicle performance for ISS missions; examples include improved main engine turbopumps and main combustion chambers, lightweight aluminum-lithium external tank, and improved avionics.

In May 2000, the *Atlantis* flight featured a new Phase One upgrade: the MEDS. This subsystem replaces the old "green screen" monitors (cathode ray tubes) and many flight deck controls. The other orbiters are scheduled for the MEDS installation by 2003. MEDS is expected to dramatically reduce simulator-training time and improve contingency response.

Phase Two upgrades are low-cost, high-value, incremental enhancements; examples include installation of a micro-meteoroid and orbital debris protection system and the replacement of launch control room systems.[39] Additional long-range performance and safety upgrades are also under consideration, including a crew escape module and the use of liquid-fueled fly-back booster rockets or five-segment solid rocket boosters.

X-33

Vehicle: X-33

Developer: NASA, Lockheed Martin

First launch: 2003

Number of stages: 1

Payload performance: None

Launch site: Edwards AFB, CA

Markets served: Testbed for RLV technologies and operations

The X-33 program was initiated to develop a testbed for integrated RLV technologies, paving the way for full-scale development of an SSTO RLV that would be contracted for government and private sector use.[40] The X-33 is targeted to reach high hypersonic speeds and demonstrate SSTO and autonomous operations capabilities. NASA has set goals of a seven-day turnaround time and a two-day 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.

In April 1995, NASA signed cooperative agreements with Lockheed Martin, McDonnell Douglas, and Rockwell International to develop concept designs for the X-33 program. On July 2, 1996, NASA selected Lockheed Martin's aeroballistic rocket design, which is essentially a lifting body. In September 2000, NASA and Lockheed Martin agreed to continue with the program despite significant problems incurred with the development of composite hydrogen tanks and other setbacks. The September agreement included a new payment schedule, inclusion of aluminum instead of composite hydrogen tanks, and a target launch date of 2003. By December 2000, Lockheed Martin had assembled 75 percent of the vehicle and had fabricated, tested, and delivered 95 percent of the vehicle's components to its Palmdale, California, facility.[41]

The X-33 will measure about 21 meters in length and have a dry mass of about 34,000 kilograms.[42] The X-33 will be powered by two linear aerospike engines under development by Boeing's Rocketdyne division. These engines do not use conventional cone-shaped exhaust nozzles but allow the exhaust flow to adjust to changes in atmospheric pressure. Fourteen tests of a single aerospike engine were successfully completed in 2000. A series of tests involving the two flight engines in tandem for X-33 are planned for the first half of 2001.[43]

The flight test facility at Edwards AFB in California was completed in November 1998. The X-33 rotating launch platform at Edwards AFB was validated with a 31,750-kilogram simulator in February 1999. In addition, the translating shelter, ground electrical supplies, and storage systems were activated.[44] Test flights of the X-33 will launch from the eastern portion of Edwards AFB and land at Michael Army Air Field in Utah and Malmstrom AFB near Great Falls, Montana. In parallel with these activities, Kennedy Space Center (KSC) validated a new laser-guided vehicle positioning system for the X-33.[45]

Vehicle: X-34

Developer:NASA, Orbital Sciences Corp.

First powered launch: 2002

Number of stages: 1

Payload performance: 181-kg payload allocation

Possible launch sites: Edwards AFB, CA; Kennedy Space Center, FL

Markets served: Testbed for RLV technologies and operations

X-34

The X-34 is designed as a sub-orbital testbed for technologies and operations that may be incorporated into future RLVs. Other goals for the X-34 are to reduce launch costs and use a ground and support team of twelve to launch twice within a two-week timeframe.[46] The X-34 program, initiated by NASA in 1994 and currently managed by Marshall Space Flight Center, includes three test vehicles being built by Orbital Sciences Corporation.

The first vehicle, designated A-1A, is an unpowered flight vehicle. The A-1A was successfully tested in 2000 during captive-carry flight attached to the belly of a modified L-1011 aircraft. The vehicle is currently undergoing twelve ground tests to examine roll-out characteristics, verify guidance and navigation, and evaluate nose wheel steering and braking. Captive flights with the A-1A will resume in 2001 to finish FAA safety certification on the flight combination with the L-1011.[47] The other two vehicles, the A-2 and A-3, are both powered vehicles. The A-2 will be flown at speeds of up to Mach 4.5 and will demonstrate crosswind landings and flight through rain. The A-3 will be flown at Mach 8 at an altitude of 76.2 kilometers with carry-on experiments.[48]

Flight testing will focus on RLV operations such as a surge capability of 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.[49]

The X-34 design features a cylindrical body with delta wings. The vehicle will measure 17.8 meters in length with a wingspan of 8.4 meters and will have a dry mass of 19,500 kilograms. After being launched from a modified L-1011 aircraft, the X-34 will achieve a maximum speed of Mach 8 and reach altitudes of up to 80 kilometers. The primary engine is a new LOX/kerosene rocket engine known as Fastrac, a power plant being designed, developed, and provided by NASA under a separate program. In August 1999, NASA, having concluded the development of the engine, awarded a contract to Summa Technology Incorporated to manufacture three Fastrac engines for the X-34 program. The contract also calls for Summa to investigate possible commercial uses of the Fastrac engine.[50]

During 1999, the program suffered a six-month setback with the unexpected announcement by the Air Force to prohibit launches from X-34's originally planned site, Holloman AFB, New Mexico. NASA and Orbital Sciences have since moved most powered flight tests to Edwards AFB and plan to use White Sands Missile Range for some unpowered approach and landing tests as well as engine static test firings.[51]

The schedule for the flight tests of the A-2 and A-3 is pending a program review by NASA prompted by failures of two Mars-bound spacecraft in 1999.[52]

Second Generation RLV

NASA released an Integrated Space Transportation Plan for current and future space transportation systems in 2000. This plan consolidates into one budgetary area a $7.2 billion plan for fiscal years 2001-2005 for Shuttle safety and technology upgrades, ongoing X-vehicle programs, technology base development, the ISS Crew Return Vehicle, and the new Space Launch Initiative (SLI) including Second Generation RLV.

The largest share of the integrated plan is the Second Generation RLV program, worth $4.5 billion through FY 2005. (The program name Second Generation RLV is often used interchangeably with SLI.) The Space Shuttle is considered to be a first generation RLV. Second Generation RLV is comprised of four budgetary areas: Systems Engineering and Requirements Definition; RLV Competition and Risk Reduction; NASA Unique System Elements (including the Crew Return Vehicle); and Alternative Access (contingency re-supply for ISS). The goal of the Second Generation program is to develop a commercially competitive, privately owned and operated RLV that serves both commercial and NASA human space flight and other unique government needs. Increasing safety and reducing the cost of access to space are key drivers of the program.

As part of Second Generation systems engineering and risk reduction research activities, NASA's Marshall Space Flight Center is evaluating proposals for NASA Research Announcement (NRA) 8-30 during the first quarter of 2001. NRA 8-30 includes ten technology areas for future RLV architectures including flight demonstrations.

Around April 2001, NASA will award contracts for NRA 8-30 for continued study, possibly including three or four vehicles and various RLV supporting technologies. Next, NASA will continue to refine programmatic, business, and technical risks to enable at least two competing vehicle options by 2005. NASA plans to proceed with full-scale development for at least one RLV to be operational by 2010. If the market can support more than one new RLV, NASA hopes to develop an architecture that can benefit from multiple commercial providers.[53]

NASA is studying whether the Crew Return Vehicle could be outfitted as an ascent vehicle in combination with a future RLV or an ELV in conjunction with NRA 8-30.
The Alternative Access program will enable NASA to supply ISS through commercial launch providers, opening up a potential new market for future RLVs and existing ELVs, if NASA chooses to exercise a launch services contract. Light missions delivering cargo to ISS carry around 500 kilograms; heavier missions could carry 2,000 kilograms. Industry study contracts were completed in 2000. NASA is also evaluating rendezvous operations with ISS.

Research and development of third generation RLV technologies including advanced propulsion will also continue as part of the overall Integrated Space Transportation Plan.
SLI received $290 million for FY 2001 from Congress as a new start program for fiscal year 2001 when President Clinton signed in October 2000 the VA-HUD-Independent Agencies Appropriations bill that includes NASA.

Vehicle	First launch	Manufacturer/ Developer (website)	Number of stages	Powerplants	Performance	Launch method	Recovery method	Launch Contracts	Government funding	Potential Markets Served	Subcontractors	Commercial Investors	Possible launch sites
United States Commercial Programs													
2nd Generation Reusable Launch Vehicle	post-2006	Kelly Space and Technology (www.kellyspace.com)	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	4,700 kg to 300 km 28.5 deg. LEO 3,950 kg to 300 km 86 deg. LEO 3,400 kg to 1700 km 28.5 deg. LEO 2,700 kg to 1700 km 86 deg. LEO 2,072 kg to GTO	air-launched	horizontal landing	no	no	Launch of humans and cargoes to all conventional orbits	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		East/West/Gulf Coast locations, eventually mid-continent
K-1	TBD	Kistler Aerospace Corporation (www.kistleraerospace. com)	2	First stage: 3 GenCorp Aerojet AJ-26 kerosene/ LOX engines Second stage: 1 GenCorp Aerojet AJ-60 kerosene/ LOX engine	Standard Payload Module: 4,000 kg to 400 km 45 deg. LEO 2,100 kg to 1,000 km 45 deg. LEO 2,250 kg to 400 km 98 deg. LEO Extended Payload Module: 3,700 kg to 400 km 45 deg. LEO 1,900 kg to 1000 km 45 deg. LEO 2,000 kg to 400 km 98 deg. LEO 1,570 kg to GTO with use of an Active Dispenser 2,500 kg cargo up-mass to ISS 900 kg cargo down-mass from ISS	vertical launch	parachutes and air bags (both stages)	yes	no	Launch of LEO payloads, launch of GTO and other high energy payloads, ISS resupply and cargo return missions	GenCorp Aerojet, Northrop Grumman Corporation, Lockheed Martin Space Systems Company - Michoud Operations, Draper Laboratories, Honeywell, Irvin Aerospace, Inc., Oceaneering Thermal Systems	Kistler Aerospace has raised more than $500 million in private capital, and continues to seek commercial financing to complete the K-1. Northrop Grumman has invested $30 million, with options for additional investment. Space Systems/Loral has signed a contract worth in excess of $100 million with Kistler Aerospace for ten launches. Space Operations International signed a MOU for launch of secondary payloads.	Woomera, Australia; Nevada Test Site, NV
Pathfinder	TBD	Pioneer Rocketplane (www.rocketplane.com)	2	2 GE F404 turbofan engines, 1 RD-120 LOX/kerosene engine	2,100 kg to 200 km Equatorial 1,600 kg to 200 km Polar 1,900 kg to 1,000 km Equatorial 1,450 kg to 1,000 km Polar	horizontal takeoff	horizontal landing	no	yes	Launch of small and medium-class LEO payloads	Scaled Composites, ARB Rockets Incorporated		Oklahoma Spaceport; Vandenberg AFB, CA; Cape Canaveral, FL
Roton	-	Rotary Rocket Company (www.rotaryrocket.com)	1	Cluster of several engines derived from the Fastrac design	3,600 kg to 275 km 35 deg. LEO 2,700 kg to 370 km 90 deg. LEO 3,150 kg to 550 km 35 deg. LEO 2,250 kg to 550 km 90 deg. LEO	vertical launch	vertical landing	yes	no	Launch of LEO constellation satellites and crew transfer to and from space stations	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	Space Operations International signed a MOU for launch of secondary payloads.	TBA
SA-1	2007	SPACE ACCESS®, LLC	2 (LEO) 3 (GTO)	Ejector LOX/hydrogen ramjets for each stage	15,000 kg to LEO 5,200 kg to GTO	horizontal takeoff	horizontal landing	no	yes	Launch of medium to heavy LEO and GTO payloads, launch of ISS resupply missions, human spaceflight	Kaiser Marquardt, undisclosed "major aerospace firms"		Brazoria/Sarita Spaceports, TX; Homestead ARB/Kennedy Space Center, FL
Space Cruiser System (SCS)	post-2003	Vela Technology Development, Inc. Space Adventures (www.spaceadventures. com)	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	TBD	Lockheed Martin (www.venturestar.com)	1	7 RS-2200 linear aerospike engines	22,700 kg to LEO	vertical launch	horizontal landing	no	yes	VentureStar launch of heavy-class LEO and GTO payloads			Multiple states are bidding to have a VentureStar site
United States Government Programs													
Space Shuttle	1981	Rockwell, Rocketdyne, Lockheed Martin (www.boeing.com) (www.lmco.com)	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	vertical launch	horizontal landing	yes	yes	Science missions, experimental payloads, human spaceflight, launch and in-orbit retrieval and repair of spacecraft			Kennedy Space Center, FL
X-33	2003	Lockheed Martin (www.venturestar.com)	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, BF Goodrich Aerospace, Honeywell, Alliant Techsystems, Jacobs Sverdrup, Boeing Rocketdyne		Edwards AFB, CA
X-34	2002	Orbital Sciences Corporation (www.orbital.com)	1	One kerosene/LOX Fastrac engine	Mach 8 at 76 km (vehicle A3) 181-kg payload allocation	air-launched	horizontal landing	no	yes	Sub-orbital demonstration of RLV technology	AlliedSignal, Oceaneering Incorporated, Draper Laboratories, Summa Technology Inc.		Edwards AFB, CA; Kennedy Space Center, FL

X PRIZE® Competitors

The X PRIZE®

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® 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 team able to launch a vehicle capable of carrying three people to a 100-kilometer 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® 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.

The X PRIZE® competition currently has 20 entrants from five countries offering a variety of different RLV concepts. The commercial vehicles under development for the X PRIZE® competition are 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.

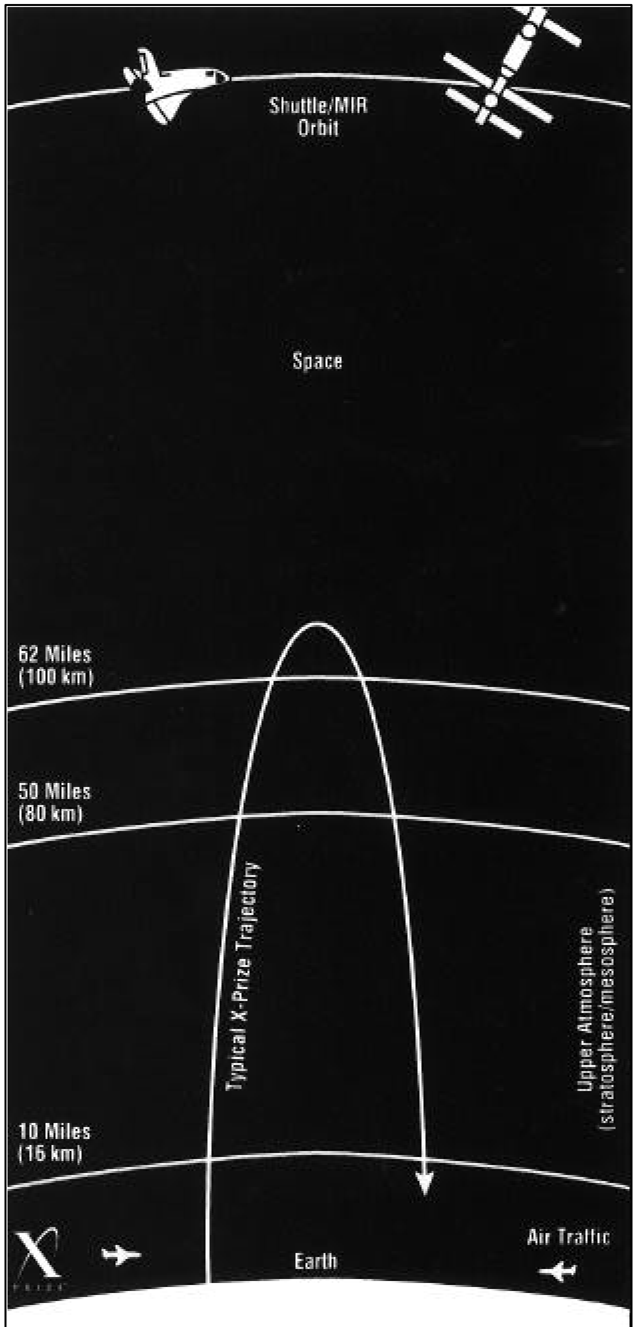


Figure 1: Typical X PRIZE℠ Trajectory

In May 1998, the Foundation unveiled the X PRIZE® trophy, which was put on display at the National Air and Space Museum in Washington, DC. During 2000, the X PRIZE® trophy was on loan to the Museum of Flight in Seattle, Washington.

Table 2: Summary of X PRIZE® Vehicles

Program	Developer	Vehicle Type
Ascender	David Ashford, Bristol Spaceplanes Limited (Bristol, England)	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 (San Bernardino, CA)	Horizontal takeoff and landing vehicle that is towed to an airborne launch site by a modified Boeing 747.
Aurora	Fundamental Technology Systems (Altamonte Springs, FL)	Horizontal takeoff and landing double delta spaceplane powered by a single throttleable kerosene and hydrogen peroxide engine.
Canadian Arrow	Canadian Arrow (Ontario, Canada)	Vertically launched two-stage vehicle with water landing of both booster and passenger stages.
Cosmos Mariner	Dynamica Research (Houston, TX)	Spaceplane powered by two airbreathing engines and one rocket engine. The vehicle will launch and land horizontally.
Gauchito	Pablo De Leon and Associates (Argentina)	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 (London, England)	Cylinder-shaped rocket using liquid-fueled rocket engines. The vehicle will launch vertically and land vertically using parachutes and air bags.
Kitten	CFFC, Inc. (Oroville, WA)	Methane and LOX powered spaceplane that takes off and lands from conventional runway. Structure is aluminum sandwich foam with Boron Nitride ceramic coating.
Lucky Seven	Mickey Badgero (Owosso, MI)	Cone-shaped vehicle powered by rocket engines. The vehicle will launch vertically and land using a parafoil.
Mayflower (CAC-1)	Advent Launch Services (Houston, TX)	Cylinder-shaped glider powered by liquid-fueled rocket engines. The vehicle will launch vertically from water and land horizontally in water.
MICHELLE-B	TGV Rockets (Bethesda, MD)	The vehicle will launch vertically and land vertically using ascent engines in a deep throttle mode.
PA-X2	Rick Fleeter, AeroAstro Inc. (Herndon, VA)	Cylinder-shaped vehicle using a liquid-fueled engine. The vehicle will launch vertically and land horizontally using a steerable parafoil.
Pathfinder	Pioneer Rocketplane (Ann Arbor, MI)	Spaceplane powered by both airbreathing jet engines and LOX/kerosene rocket engines. The spaceplane will take-off horizontally and meet a tanker aircraft for air-to-air refueling.
Proteus	Burt Rutan, Scaled Composites (Mojave, CA)	Two-stage vehicle consisting of the turbo-fan powered Proteus aircraft and a rocket-powered second stage.
The Space Tourist	John Bloomer, Discraft Corporation (Portland, OR)	Disc-shaped vehicle powered by airbreathing "blastwave-pulsejets." The vehicle will take off and land horizontally.
Thunderbird	Steven M. Bennett, Starchaser Foundation (Cheshire, England)	Cylinder-shaped rocket using airbreathing engines and liquid fueled rocket engines. The vehicle will launch and land vertically.
X Van	Pan Aero, Inc., Third Millennium Aerospace (Washington, DC)	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.

Table 2: Summary of X PRIZE® Vehicles (continued)

Program	Developer	Vehicle Type
Unnamed	William Good, Earth Space Transport System Corporation (Highlands Ranch, CO)	No information on this entry has been released.
Unnamed	Cosmopolis XXI (Moscow, Russia)	Cylinder-shaped rocket which is launched from a carrier aircraft “Geophisika.” The vehicle will take off vertically and land horizontally.
Unnamed	The da Vinci Project (Ontario, Canada)	Air-launched, LOX/kerosene rocket deployed from large piloted hot air balloon. Recovery system features a high drag reentry ballute and parachute. Air bags are used to cushion touchdown on landing.

During 2000, the X PRIZE® Foundation made progress in attracting sponsors and new entrants.[54] The foundation worked with several non-U.S. groups to encourage greater international participation in the competition. Two of the four new X PRIZE® entrants come from Canada. The first of these designs, proposed by the da Vinci team, features air launch from beneath a large, piloted hot air balloon. The other Canadian team is designing the Canadian Arrow, a vertically launched two stage vehicle. The new entrants for 2000 also include the Aurora vehicle, sponsored by Fundamental Technology Systems, and the Kitten vehicle, sponsored by the Cerulean Freight Forwarding Company. Both vehicles are being designed for horizontal take-off and landing.

In addition to the announcements of four new vehicle entries to the X PRIZE® competition, two teams took steps forward in developing their vehicles in 2000. On July 6, 2000, the Starchaser Foundation team successfully launched a two-stage rocket to test a launch escape system and avionics for the Thunderbird vehicle. The six-meter rocket was launched from Morecambe Bay, United Kingdom, to an altitude of 5.8 kilometers.[55] Pablo de Leon and Associates were also busy throughout 2000 managing a vigorous hybrid rocket development program. The Argentine team has been successfully testing sub-scale solid/liquid rocket motors. Hybrid rockets will be used in the propulsion system of their Gauchito vehicle.[56]

Several of the competitors have commercial plans for their vehicles after the X PRIZE®. In addition to the already discussed plans of Pioneer Rocketplane and Kelly Space and Technology, Scaled Composites plans to use its Proteus aircraft for atmospheric research, reconnaissance, microsatellite launch, and as a telecommunications platform over metropolitan areas.[57] The Mayflower and Ascender are planned for continued use as commercial space tourism platforms. The X Van, Cosmos Mariner, and Aurora are proposed for both satellite launch and space tourism missions.

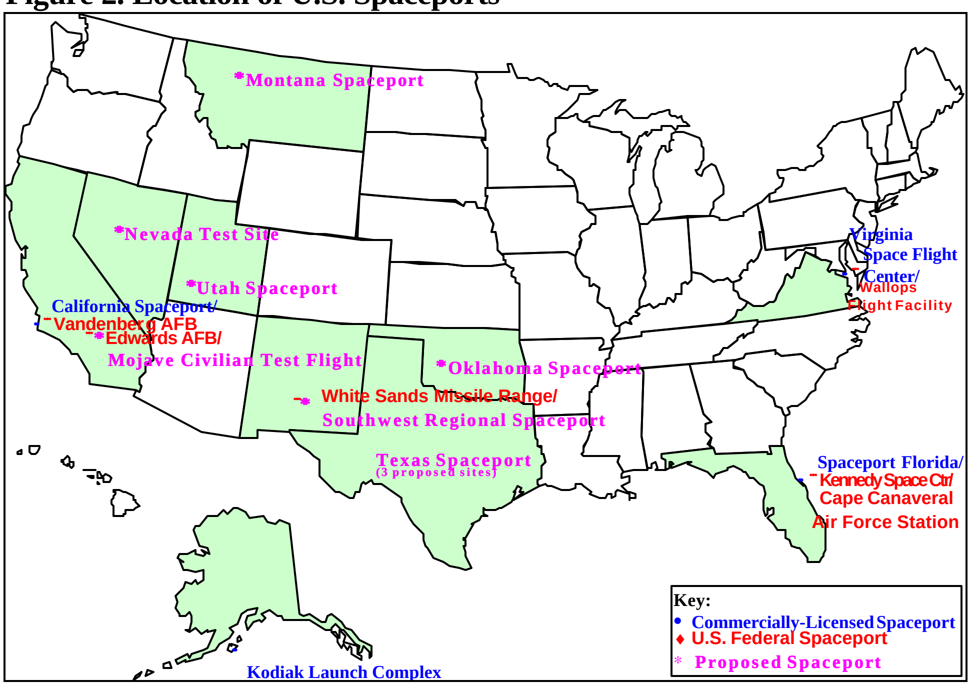
Spaceports

Since the 1950s, the U.S. government has built, operated, and maintained space launch ranges and bases to meet a variety of national needs. Although U.S. military and civil government agencies have traditionally been the primary users of this infrastructure, non-government customers, flying payloads on either government-procured or private launch vehicles, have used it as well. Historically, NASA acted as the primary intermediary between government space launch ranges and non-governmental entities using these assets. However, after the 1986 *Challenger* accident, the White House made a decision to allow launch customers to solicit bids directly from private sector launch vehicle manufacturers. These vehicle manufacturers, in turn, began to use or lease launch facilities from NASA or the U.S. Air Force under the terms of the 1984 U.S. Commercial Space Launch Act and its 1988 amendments.

Today, the increasing commercialization of the U.S. launch industry is evident not only in the growing numbers of commercially procured launches but also in an expanding list of commercial launch sites supplementing U.S. government operated sites. The very first launch from a U.S. commercial launch site, Spaceport Florida, took place in January 1998. Today, four currently licensed commercial launch sites exist. States are encouraging the development of further commercial launch sites through a variety of grants and legislative activities.

This section describes existing and emerging launch sites, otherwise known as spaceports. It is divided into three subsections: Commercially Licensed Spaceports, U.S. Federal Spaceports, and Proposed Spaceports. Figure 2 shows the location of these spaceports, and Table 4, located at the end of this section, summarizes each spaceport's major characteristics.

Figure 2. Location of U.S. Spaceports



With the exception of the facilities that have served the Space Shuttle, the existing spaceports have only interfaced with ELVs to date. Many existing and developing federal and commercial spaceports, however, plan or aspire to serve some of the RLVs currently under development. The spaceports' potential and planned involvement with RLVs is discussed in the subsections.

Commercially-Licensed Spaceports

In order to conduct a commercial space launch from or operate a commercial launch site in the United States, it is necessary to obtain a license from the federal government. FAA/AST issues such licenses to conduct individual launches or to operate commercial launch sites. While the vast majority of licensed launch activity still occurs at U.S. federal ranges, much future launch activity is expected to originate from private or non-federally-operated launch sites. To date, FAA/AST has licensed four non-federal launch sites, including the California Spaceport at Vandenberg AFB (VAFB), Kodiak Launch Complex (KLC) in Alaska, Spaceport Florida at Cape Canaveral Air Force Station (CCAFS), and the Virginia Space Flight Center (VSFC) at Wallops Flight Facility (see Table 3). The first orbital launch from an FAA/AST licensed site occurred on January 6, 1998, when a Lockheed Martin Athena 2 carrying NASA's Lunar Prospector spacecraft successfully lifted off from Spaceport Florida.

Table 3. Launch Site Operator Licenses Issued

License	Operator / Launch Site	Location	Original Effective Date	Expiration Date
LSO 96-001	Spaceport Systems International / California Spaceport	Vandenberg Air Force Base	19 Sep 1996	19 Sep 2001
LSO 97-002	Spaceport Florida Flight Authority / Spaceport Florida	Cape Canaveral Air Force Station	22 May 1997	22 May 2002
LSO 97-003	VA Commercial Space Flight Authority / Virginia Space Flight Center	Wallops Flight Facility	19 Dec 1997	19 Dec 2002
LSO 97-004	Alaska Aerospace Development Corporation / Kodiak Island	Kodiak Launch Complex	24 Sep 1998	24 Sep 2003

California Spaceport

Based near Lompoc, California, the California Spaceport is a commercial launch services company operated and managed by Spaceport Systems International, L.P., a limited partnership between ITT Federal Services Corporation and California Commercial Spaceport, Incorporated. It is co-located with VAFB on the central California coast where Spaceport Systems International has signed a 25-year lease. On September 19, 1996, the California Spaceport became the first commercial launch site to be licensed by FAA/AST. Located at 34° North latitude, the California Spaceport can support a variety of mission profiles to low polar orbit inclinations, with possible launch azimuths ranging from 220° to 150°.

Initial construction at California Spaceport's Commercial Launch Facility began in 1995 and was completed in 1999. The current facility design concept is based on a "building block" approach. Power and communications cabling is routed underground to provide a "flat pad" with the flexibility to accommodate a variety of different launch systems. Although the facility currently is configured to support solid propellant vehicles, plans are in place to equip the facility with commodities required by liquid fueled boosters. The current configuration of the facility consists of the following infrastructure: pad deck, support equipment building, launch equipment vault, launch duct and stand, communications equipment, and launch control room. Final facility configuration awaits customer requirements. When fully developed, the facility will be able to accommodate a wide variety of launch vehicles including the Minuteman-based Minotaur and Castor 120-based vehicles.

Originally, the focus of the California Spaceport's payload processing services was on the refurbishment of the Payload Preparation Room. This is a cleanroom facility designed to process three Space Shuttle payloads simultaneously. It is now leased and operated by the California Spaceport as the Integrated Processing Facility.

With the Commercial Launch Facility and the Integrated Processing Facility, the California Spaceport provides both payload processing and orbital launch support services for commercial and government users. The California Spaceport provided payload-processing services for the NASA Lewis satellite and has contracts to provide payload processing for two Earth Observation System satellites. The California Spaceport's first orbital launch occurred when it supported the launch of JAWSAT (a joint project by the Air Force Academy and Weber State University) on a Minotaur launch vehicle in July 2000.

Kodiak Launch Complex

In 2000, the Alaska Aerospace Development Corporation (AADC) completed two years of construction of the Kodiak Launch Complex (KLC), the first new U.S. launch site since the 1960s and the only FAA-licensed spaceport not co-located with a federal launch site. A joint NASA-Department of Defense mission on a Lockheed Martin Athena 1, planned for 2001, is scheduled to be the first orbital launch from Kodiak.

AADC was created as a public company in 1991 by the Alaska state legislature. KLC has received funding from the U.S. Air Force, U.S. Army, NASA, the State of Alaska, and private firms. The commercial spaceport at Narrow Cape on Kodiak Island is about 420 kilometers south of Anchorage and 40 kilometers southwest of the city of Kodiak. It is located on a 12.4-square-kilometer site owned by the State of Alaska and divided between four areas: 1) the launch control and management center; 2) the payload processing facility (which will include a class-100,000 cleanroom, an airlock, and a processing bay; 3) the integration and processing facility/spacecraft assemblies transfer facility; and 4) the launch pad and service structure. These facilities will allow the transfer of vehicles and payloads from processing to launch without exposure to the outside environment. This will protect both the vehicles and those working on them from exterior conditions, allowing all-weather launch operations.

The AADC is also supporting the development of ground station facilities near Fairbanks, Alaska, in cooperation with several commercial remote-sensing companies. The high-latitude location makes the Fairbanks site favorable for polar orbiting satellites, which typically pass above Fairbanks several times daily. Mobile tracking equipment is currently provided by NASA's Wallops Flight Facility.

Located at 57° North latitude, KLC provides a wide launch azimuth and unobstructed downrange flight path to the south over the Pacific Ocean. KLC's planned markets are telecommunications, remote sensing, and space science payloads of up to 3,600 kilograms. These can be delivered into LEO, polar, and Molniya orbits. The first launch from Kodiak was a suborbital vehicle, Ait-1, built by Orbital Sciences Corporations for the U.S. Air Force in November 1998. A second Ait launch followed in September 1999.

KLC also intends to provide support for RLV operations as these vehicles are developed and deployed.

Spaceport Florida

Established in 1989, the Spaceport Florida Authority (SFA) was created by the State of Florida to facilitate the development of Florida's space-related industry. The SFA facility consists of about 28 hectares of land at Cape Canaveral Air Force Station (CCAFS) owned by the U.S. Air Force and operated by the U.S. Navy's Strategic Systems Program Office. The SFA was awarded a commercial launch site license by FAA/AST on May 22, 1997.

Under an arrangement between the federal government and SFA, underutilized facilities at CCAFS have been conveyed to SFA for improvement and provision to commercial users on a dual-use, non-interference basis with U.S. Air Force programs. SFA's efforts have concentrated on CCAFS's Launch Complex (LC) 46, an old Trident missile launch site. LC 46 has been modified to accommodate small commercial launch vehicles as well as the U.S. Navy's Trident. The philosophy guiding the development of LC 46 was to build a public transportation infrastructure for several competing launch systems rather than to tailor a facility for a single launch system. As a result, LC 46 can currently accommodate a variety of launch vehicle configurations with lift capacities of up to 1,800 kilograms to LEO. In the future, LC 46 could accommodate vehicles carrying payloads in excess of

2,200 kilograms to LEO. Launches to geostationary and interplanetary trajectories can also be conducted from this site.

Currently, LC 46 is configured for Castor 120 or similar solid-motor-based vehicles (examples include Lockheed Martin's Athena and Orbital Sciences Corporation's Taurus). Its infrastructure can support launch vehicles with a maximum height of 36 meters and diameters ranging from 1.3 to 3.1 meters. A Lockheed Martin Athena 2 carrying NASA's Lunar Prospector was the first vehicle to be launched into orbit from Spaceport Florida in January 1998.

SFA has also recently upgraded LC 20, made up of former Titan 1, Titan 2, and suborbital pads, to service a variety of small launch vehicles for both orbital and suborbital launches. LC 20 includes three launch pads, a launch control blockhouse, and an on-site facility for small payload preparation and storage. SFA hopes to use these facilities to provide a rapid response capability for various types of LEO payloads. SFA plans to refurbish the LC 20 blockhouse to offer a multi-user launch control and data monitoring system that will serve a variety of vehicle and payload systems.

With its location on CCAFS, Spaceport Florida can offer extensive support services using existing range infrastructure. In addition to CCAFS assets required to conduct launch operations (such as range tracking and telemetry equipment), payload processing facilities—including cleanrooms—are available from off-site commercial providers.

Thus far the SFA has invested over $500 million in new space industry development. It has upgraded LC 46 and LC 20, built an RLV Support Complex (adjacent to the Shuttle landing site on KSC grounds), developed a new space operations support complex, and supported the Homestead Spaceport Initiative. It has also financed the Atlas 5 evolved expendable launch vehicle (EELV) launch facilities at CCAFS; financed and constructed a Delta 4 EELV Horizontal Integration Facility for Boeing; and provided financing for a Titan 4 storage/processing facility.

Virginia Space Flight Center

The Virginia Space Flight Center (VSFC) traces its beginnings to the Center for Commercial Space Infrastructure (CCSI), which was created in 1992 at Virginia's Old Dominion University to establish commercial space research and operations facilities in the Commonwealth of Virginia. CCSI worked in cooperation with NASA's Wallops Flight Facility on Wallops Island, Virginia, to develop a commercial launch infrastructure at Wallops. In 1995, CCSI grew into the Virginia Commercial Space Flight Authority (VCSFA).

VCSFA is a public organization focused on developing a commercial launch capability in Virginia. In 1997 VCSFA signed with NASA the NASA/VCSFA Reimbursement Space Act Agreement to use NASA's Wallops facilities in support of commercial launches. This 30-year agreement allows the Authority access to the NASA Wallops payload integration, launch operations, and monitoring facilities on a non-interference, cost-reimbursement basis. On December 19, 1997, FAA/AST awarded VCSFA a commercial launch site operator's license for the VSFC, which it operates in cooperation with NASA.

VSFC is not the first commercial venture at Wallops. In 1994, EER Systems of Seabrook, Maryland, built launch pad 0-A at Wallops for use by EER Systems' Conestoga launch vehicle. The Conestoga's first and only attempted launch from this location took place in Fall 1995, when it failed to orbit the METEOR microgravity payload. Launch pad 0-A is still owned by EER Systems.

VSFC's current facilities can support a variety of solid-fueled vehicles. Future development plans include completion of the commercial facilities at launch pad 0-B. Pad 0-B is designed as a "universal launch pad," capable of supporting a variety of small- and medium-sized launch vehicles. It will consist of a 1,767-square-meter pad and a 55.5-meter service tower, equipped with a 68-metric-ton crane for vehicle and payload handing. Phase I construction (including the pad, launch mount, and some additional supporting infrastructure) was begun in early 1998 and was completed in December of that year.[58] The service tower will be developed in subsequent development phases. From its location on Virginia's southeastern Atlantic coast, VSFC can accommodate a wide range of orbital inclinations and launch azimuths. The most likely user vehicles for the facility are Lockheed Martin's Athena or Orbital Sciences Corporation's Taurus.

U.S. Federal Spaceports

The bulk of U.S. orbital launches are conducted from the federal launch ranges: CCAFS or Kennedy Space Center (KSC) in Florida and VAFB in California. With the transition underway to EELV, the number of launch pads utilized by Delta, Atlas, and Titan at both sites will eventually decrease from ten to four standardized pads, although some currently active vehicles such as Delta 2 may continuing launching as long as the market demands.

Since the mid-1980s the federal ranges have supported commercial launch activity. Anticipating a continuing increase in the number of commercial launches from these sites and recognizing that the ranges are aging, the U.S. government is engaged in range modernization. This effort includes the ongoing Range Standardization and Automation program, a key effort to modernize and upgrade the Eastern Range at CCAFS and portions of the Western Range at VAFB. Launch pad development with commercial and state government support is also continuing for the latest generation of the Delta and Atlas launch vehicles (the Delta 3 and the Atlas 3) and the upcoming EELVs (the Delta 4 and Atlas 5 families).

Cape Canaveral Air Force Station/Kennedy Space Center

CCAFS and NASA's Kennedy Space Center (KSC) are co-located on the "Florida Space Coast" at Cape Canaveral along with the commercially oriented Spaceport Florida. The Cape Canaveral area has endured several name changes. In 1949, the Banana River Naval Air Station was transferred to the U.S. Air Force for use as a joint service missile range. NASA's Launch Operations Center was renamed Kennedy Space Center in 1963. Air Force Space Command redesignated Cape Canaveral Air Station as Cape Canaveral Air Force Station in February 2000.

The Cape developed rapidly during the space race of the 1950s and 1960s supporting Mercury, Gemini, and Apollo programs as well as ballistic missile testing.

Today, CCAFS encompasses six active launch pads for Delta, Atlas, Titan and Athena launch vehicles while the Space Shuttle operates from two pads at KSC. Range support for military, civil, and commercial launches is managed by the 45th Space Wing, headquartered at nearby Patrick AFB. The Eastern Range extends some 16,000 kilometers over the Atlantic Ocean. NASA oversees launch operations for the Space Shuttle while the 45th Space Wing conducts flight operations for launches from CCAFS.

There is currently one active launch pad (LC 40) for remaining Titan 4 vehicles launching from the East Coast. In 1999, Lockheed Martin began to work on new facilities for Atlas 5 at LC 41 including the implosion of the launch tower used by Titan 4. The SFA entered into an arrangement for ownership of LC 41 and support integration facilities and will lease them to Lockheed Martin. Boeing has a similar agreement with Spaceport Florida for lease of LC 37 and integration facilities where future launches of Delta 4 will occur. LC 37 has been inactive since 1960s when it served as the site for eight Saturn 1 and Saturn1B launches.

KSC maintains its own launch complex, LC 39. LC 39's pads A and B were originally built to support the Apollo program. After the end of the lunar landing program in 1972, they served to launch Skylab, Apollo-Soyuz, and now the Space Shuttle. LC 39 launch and processing facilities are all located on Meritt Island, between the Florida mainland and Cape Canaveral. LC 39 support facilities include the Vehicle Assembly Building, the Launch Control Center, the Mobile Launcher Platform, the Crawler Transporter, the Orbiter Processing Facilities, the Payload Processing Facility, and the Shuttle Landing

Facility, all of which are now dedicated to the Space Shuttle. KSC also provides a Range Operation Control Center, five hangars for non-hazardous payload processing, the Shuttle Payload Integration Facility, the Satellite Assembly Building, and an Explosive Safe Area.

KSC (along with Spaceport Florida) has been selected as the launch and landing base for the X-34's second phase of powered testing. Primarily to support X-34 operations, but also in the hope of attracting more RLV business, the State of Florida (through the SFA) has financed the construction of a climate-controlled hangar and processing facility at KSC (see the Spaceport Florida section).

Edwards Air Force Base

Edwards AFB in Mojave, California, is the home of the NASA Dryden Flight Research Center and the Air Force Flight Test Center.

Edwards AFB served as the initial Space Shuttle landing site. The first two Shuttle flights landed on Rogers Dry Lake, a natural hardpack riverbed about 114 square kilometers in size. A 4.5-kilometer runway was built at Edwards after flooding of the normally dry lakebed in 1982 rendered the site unavailable for the third-ever Shuttle landing (the Space Shuttle instead landed at White Sands, New Mexico that time). Today, NASA prefers to use KSC as the Shuttle's primary landing site and uses Edwards as a back-up site.

The X-33 Program Office has built a launch site at Edwards. Completed in December 1998, this 12-hectare complex consists of an X-33-specific launch pad, the Operation Control Center, and a movable hangar where the vehicle is to be housed and serviced in a horizontal position. The X-33 launch site is equipped with hydrogen and nitrogen gas tanks as well as liquid hydrogen and oxygen tanks capable of holding more than 1.1 million liters of cryogenic materials. A 76-meter-tall water tower will supply nearly a million liters of water to the concrete flame trench during launch. This deluge system not only is a cooling mechanism but also serves as a sound suppression system and helps minimize the intensity of the shock-wave rebounding from the trench to the engine.[59] The Operation Control Center, which will serve as a launch monitoring facility and mission control, is situated over a kilometer away from the launch pad with data and communication links to the systems at the launch site. X-33 telemetry and tracking functions will be performed using existing U.S. Air Force and NASA facilities at Edwards AFB and downrange at Wallops.

Edwards AFB, with NASA Dryden, also hosts other NASA reusable x-vehicle demonstration programs. The X-34 high speed and long-range flight program will occur at Edwards. The X-37 will be tested at Edwards, culminating in a landing after an orbital space test (scheduled for a Shuttle launch in 2003). Testing of X-38, a demonstrator for the ISS Crew Return Vehicle; continues at Edwards, which may also serve as the vehicle's landing site. In 2001, the U.S. Air Force and NASA plan to conduct drop tests of the X-40A demonstrator for the proposed Space Maneuver Vehicle. Also in 2001, NASA plans the first X-43 (Hyper-X) flight; the vehicle will be carried by a B-52 from Edwards to a site over the Pacific Ocean where X-43 will launch suborbitally from the nose of a two-stage Pegasus.

Vandenberg Air Force Base

Located in Lompoc, California, Vandenberg AFB (VAFB) is used for polar space launches as well as missile and aeronautical testing. Activated as Camp Cook by the Army in 1941 and transferred to the U.S. Air Force in 1957, VAFB was given its name in 1958. It is the headquarters of the 30th Space Wing, which conducts space and missile launches and operates the Western Range. The range is a coverage zone that extends into the Pacific Ocean as far west as the island of Kwajalein with boundaries to the north as far as Alaska and to the south near Central America.[60] Vandenberg has a 4.5-kilometer runway, launch facilities, payload processing facilities, tracking radar, optical tracking and telemetry facilities, and control centers.

The 399-square-kilometer base houses 53 government organizations and 49 contractor companies in 1,100 buildings. VAFB hosts a variety of federal agencies and is actively trying to attract commercial aerospace companies and activity including the California Spaceport effort (see the California Spaceport section).

Current launch vehicles using VAFB include Atlas 2, Delta 2, Titan 4, Titan 2, Taurus, Minotaur, and Pegasus XL. Space Launch Complex 2, from which Delta 2 launches, is owned by NASA. Construction is underway at Space Launch Complex 6 for Delta 4 and at Space Launch Complex 3 West for Atlas 5. Payloads for Pegasus launches are integrated at Orbital Sciences' facility at Vandenberg and then flown to various worldwide launch areas.

VAFB has been contacted by two RLV developers: Pioneer Rocketplane and Kelly Space and Technology. Both have expressed interest in using VAFB facilities for testing purposes and possibly for launch activities once the testing sequence is completed. Pioneer Rocketplane signed an Initial Support Agreement with VAFB and obtained a "right-of-entry" to VAFB facilities. This permit has, however, expired and Pioneer has moved its offices off base. Kelly Space and Technology has expressed its intention to use VAFB facilities for testing purposes, but Kelly and VAFB have not yet signed an Initial

Support Agreement. Kelly plans to move its operations to privately operated facilities when once it has developed an operational vehicle.[61]

Although there are no definite plans for other RLVs to use VAFB, the base is attempting to capture more RLV business and has presented a proposal to Lockheed Martin to provide services for VentureStar™. VAFB is also being considered as a site for the proposed military Space Operations Vehicle.

Wallops Flight Facility

NASA has operated a sounding rocket range at Wallops Island, Virginia, since 1945 and has conducted over 14,000 small rocket launches. The first orbital launch was in 1961, when a Scout launch vehicle deployed Explorer 9 to study atmospheric density. There have been 29 orbital flight attempts from Wallops including six Pegasus launches, the most recent in 1999. The retired Scout made its last orbital launch from Wallops in 1985.

In addition to NASA's operations, EER Systems built launch pad 0-A to support its Conestoga launch vehicle. In 1995 the first and only flight of Conestoga failed to deploy METEOR, a satellite designed for microgravity experiments.

Other orbital launches from Wallops have included Orbital Sciences' Pegasus (beginning with the 1996 FAA/AST licensed launch of MSTI). In April 1996 the U.S. Air Force designated Wallops Flight Facility as a launch site for converted Minuteman II missiles under the Orbital/Sub-orbital Program (along with KLC and the California Spaceport), so possible future launches include the U.S. Air Force/Orbital Sciences Minotaur launch vehicle developed under that program. Wallops assets also support aeronautical testing and U.S. Navy testing.

Although Wallops has not conducted any orbital flights (beyond support of the air-launched Pegasus) since the Conestoga failure in 1995, NASA is committed to maintaining the existing infrastructure that would be used by both orbital and suborbital missions. Five launch areas (including one for heavy lift sub-orbital rockets and one for classified payloads), two blockhouses, and preparation facilities are operational. Wallops launches about 10 to 20 suborbital vehicles per year. It is part of the Eastern Range and supports northerly launches from KSC or CCAFS as well as worldwide orbital and suborbital launches with portable tracking and telemetry equipment. Wallops equipment will be used to support X-33 suborbital launches and the first orbital launch from Kodiak, Alaska. VSFC is co-located at Wallops.

White Sands Missile Range

Situated 26 kilometers northeast of Las Cruces, New Mexico, White Sands Missile Range—which includes the NASA White Sands Flight Test Center—covers 8,100 square kilometers including the site (Trinity) of the first atomic explosion. It is operated by the U.S. Army and is used mainly for launching sounding rockets. White Sands also supports Ballistic Missile Defense Organization flight-testing and is used as a test center for rocket engines and experimental spacecraft. Facilities at White Sands include seven engine test stands and precision cleaning facilities including a class-100 cleanroom for spacecraft parts.

White Sands is also the Space Shuttle's tertiary landing site (after Edwards AFB and KSC). This landing site consists of two 11-kilometer, gypsum-sand runways.

Proposed Spaceports

Mojave Civilian Test Flight Center

The Mojave Airport was established in 1935 in Mojave, California, as a county facility with taxiways and basic support facilities suitable for general aviation. A few years later, the airport was taken over by the federal government and turned into a Marine Corps auxiliary air station. In 1961, Kern County re-acquired the facility and turned the Mojave airport into a civilian flight test center.

Rotary Rocket Company used one hectare of the Mojave site between 1998 and 2000 for manufacturing and testing. During those years, Rotary built its Rotor Test Stand and a complex that included an engineering "workshop and campus" and a high bay.[62]

Montana Spaceport

The State of Montana is aggressively pursuing the development of its space industry. Under the Montana's Department of Commerce, the Montana Space Development Authority has been established to coordinate and lead the Montana's commercial space efforts. Montana's space strategy involves creating the necessary organizational and educational infrastructure to support state space activities and ultimately constructing and licensing a commercial spaceport.

Montana is proposing to fly RLVs from a site near Great Falls, Montana, and Malmstrom AFB. Malmstrom has already been selected as a landing site for the X-33 flight test program. Montana has been working with officials from both Lockheed Martin's VentureStar™ and Rotary Rocket to bring commercial space launch to the state. Montana Space Development Authority personnel have flown to Washington to meet with FAA/AST and are in the process of obtaining a commercial spaceport license for the Great Falls site.

Nevada Test Site

The Nevada Test Site, 100 kilometers northwest of Las Vegas, was selected by Kistler Aerospace as a spaceport for the K-1 RLV in addition to their Woomera facility in order to increase scheduling flexibility and to widen the range of launch azimuths available for customers. Although it did not have any launch infrastructure as of December 1999, the Nevada Test Site has existing basic infrastructure that can be used as support facilities, such as a paved runway, water, roads, and power.

The Nevada Test Site Development Corporation obtained an economic development use permit in 1997 from the Department of Energy. Shortly after, the Corporation issued a sub-permit allowing Kistler to operate a launch and recovery operation at the Nevada Test Site.

In 1999, a task force was formed to facilitate the growth of an aerospace industry in Nevada. The development of Spaceport Nevada is actively supported by the state. The Nevada Test Site Development Corporation is interested in accommodating Lockheed Martin's VentureStar™.

Oklahoma Spaceport

The State of Oklahoma is also interested in developing a spaceport and a broader space industrial base. In 1999, the Oklahoma State legislature passed a law creating the Oklahoma Space Industry Development Authority. The Authority will promote the development of space exploration and spaceport facilities in Oklahoma. The Authority is directed by a seven-member board of directors and has already designated the old Clinton-Sherman AFB at Burns Flat as the site for a future Oklahoma spaceport. No state money has been allocated to develop such a spaceport, but the designation allows continued spaceport planning and development when funding sources are identified.

As an inland site, the Oklahoma spaceport will be limited to RLVs that will not drop stages on populated areas. The Authority has signed a MOU with Pioneer Rocketplane for Pioneer's use of the Burns Flat site.

Southwest Regional Spaceport

The State of New Mexico proposes to construct and operate the Southwest Regional Spaceport for use by private companies conducting space activities and operations. Currently planned to be located near the south central New Mexico town of Upham, the spaceport is expected to provide a full range of support for satellite launches and recoveries, scientific research, and ISS support. Vehicles to be launched from the proposed spaceport are expected to have the capability to terminate each flight without damage and to make a fully controlled soft landing under emergency conditions. No spent stages or other components would be dropped during normal flight.

Major components of the proposed Southwest Regional Spaceport include two launch complexes, a landing strip, an aviation complex, a payload assembly complex, support facilities, and a cryogenic plant.

Texas Spaceport

The State of Texas has enabled the development of one or more commercial spaceports for RLVs. The most promising sites were determined based on a detailed engineering and business evaluation of many potential sites using criteria that included 56 parameters, with the most heavily weighted criteria being public safety (consistent with the FAA/AST Spaceport Guidelines) and environmental compatibility. Two of the three candidate sites are located on the Gulf of Mexico; another is in the desert area of western Texas. The Texas spaceport site(s) will be selected in cooperation with RLV operators. The spaceport(s) will be owned and operated by a public-private sector partnership. A state law was enacted in early 1999, which provides for the Spaceport Authority.

Utah Spaceport

The Wah Wah Valley Interlocal Cooperation Entity proposes to construct and operate a commercial launch site utilizing approximately 280 square kilometers of Utah State Trust lands located 50 kilometers southwest of Milford, Utah. This proposed spaceport's mission is to provide a cost effective launch and recovery facility for SSTO RLVs.

This development of the proposed spaceport would occur over several years. The proposed project would include the construction of a new 4,575-meter-long space vehicle recovery and aircraft runway at an elevation of 1,525 meters above sea level and two space vehicle launch facilities located at 2300 meters above sea level. Additionally, assembly, testing, processing, and office facilities would be constructed.

Woomera Spaceport (Australia)

Situated 430 kilometers north of Adelaide, Australia, the Woomera Range was established jointly by the United Kingdom and Australia in 1946 to test ballistic missiles and sounding rockets. Unfortunately, the plan to make Woomera an international launch site never came to fruition as France chose to build its own site and the United Kingdom announced it would no longer use the facilities after 1976.[63] The last orbital launch from Woomera was of a British Black Arrow in 1971.

After twenty-five years of virtual inactivity, Woomera is envisioned to become the first operational commercial RLV spaceport. In 1996, Kistler Aerospace signed an agreement and 25-year lease with the Australian government giving the company the right to build and operate an RLV launch complex on

Woomera grounds at 31° South latitude. After a groundbreaking ceremony in July 1998, Kistler had to halt construction because of lack of funds. Kistler plans to begin construction of the Woomera facility once program funding is completed.[64]

At present, the Woomera range is little more than an outdated launch site and assembly building and tracking facility. However, Kistler's plans include building completely new facilities including payload processing. Also, the Australian government is hoping that Kistler's efforts will attract other RLV companies in the future and has passed a series of legislative acts in support of space-related foreign investment in the area of Woomera.

This photograph of Woomera Spaceport was taken in the 1960s. Only the concrete remains today.

Table 4: Spaceport Summary Information

Spaceport	Location	Spaceport Owner/Operator	Launch Infrastructure at Site	Current Development Status
Commercially Licensed Spaceports				
California Spaceport	Near Lompoc, California	Spaceport Systems International, L.P.	Existing launch pads, runways, payload processing facilities, telemetry and tracking equipment.	Currently in place are the concrete flame ducts, communication, electrical, and water infrastructure.
Kodiak Launch Complex	Kodiak Island, Alaska	Alaska Aerospace Development Corporation	Launch control center, payload processing facility, and integration and processing facility. Limited range support infrastructure (uses mobile equipment).	Construction completed in 2000. Ready for 2001 Athena 1 launch.
Spaceport Florida	Cocoa Beach, Florida	Spaceport Florida Authority (SFA)	Two launch complexes including pads and a control center, a small payload preparation facility and an RLV support facility.	SFA has invested over $200 million to upgrade LC 46 and 20, build an RLV support complex adjacent to the Shuttle landing facilities, and develop a new space operation support complex.
Virginia Flight Test Center	Wallops Island, Virginia	Virginia Commercial Space Flight Authority	Launch pad and service tower, payload processing facility, downrange tracking facility.	Pad 0-B was completed in December 1998. VSFC obtained a commercial license from the FAA in 1997.
Federal Spaceports				
Cape Canaveral Air Force Station/ Kennedy Space Center	Near Cocoa Beach, Florida	USAF, NASA, Florida Spaceport Authority	Telemetry and tracking facilities, jet and shuttle capable runways, launch pads, hangar, vertical processing facilities and assembly building.	Site is operational for ELVs and Space Shuttle. Development of EELV launch sites in progress. Negotiated with several commercial launch companies.
Edwards AFB	Mojave, California	USAF	Telemetry and tracking facilities, jet and shuttle capable runways, X-33 launch pad, operations control center, movable hangar, fuel tanks, water tower.	X-33 site is completed.
Vandenberg AFB	Near Lompoc, California	USAF	Launch pads, vehicle assembly and processing buildings, payload processing facilities, telemetry and tracking facilities, control center, engineering office space, shuttle-capable runway.	Site is operational for ELVs. VAFB has negotiated with several commercial launch companies.
Wallops Flight Facility	Wallops Island, Virginia	NASA	Launch pads, blockhouses and processing facilities.	Site is operational for ELVs. NASA is committed to maintaining its existing infrastructure related to orbital launches.
White Sands Missile Range	White Sands, New Mexico	US Army	Telemetry and tracking facilities, 4.5 km runway. Engine and propulsion testing facilities.	Site is operational for back-up Space Shuttle landings.
Proposed Spaceports				
Mojave Civilian Test Flight Center	Mojave, California	Mojave Airport Authority	Air control tower, runway, rotor test stand, engineering facilities, high bay building.	The infrastructure in place is part of a $5.5 million project. Development uncertain without Rotary Rocket.
Montana Spaceport	Great Falls, Montana	Montana Space Development Authority	Malmstrom AFB runway.	Montana Spaceport is primarily seeking RLV business. The Montana Space Development Authority is in the process of obtaining a commercial spaceport license for the Great Falls site.
Nevada Test Site	Nye County, Nevada	Department of Energy/Nevada Test Site Development Corporation (NTSDC)	Limited launch infrastructure at this time. Power and basic facilities available.	NTSDC has issued a sub-permit allowing Kistler to operate a launch and recovery operation. NTSDC is actively promoting the site as a spaceport for both RLVs and conventional launchers.
Oklahoma Spaceport	Washita County, Oklahoma	Oklahoma Space Industry Development Authority (OSIDA)	No launch infrastructure at this time.	OSIDA designated former Clinton-Sherman AFB at Burns Flat as the future spaceport. Budget for state approval will be voted on in 2001.
Southwest Regional Spaceport	White Sands, New Mexico	New Mexico Office of Space Commercialization	No infrastructure at this time.	Plans for this site include a Spaceport central control facility, an airfield, a maintenance and integration facility, a launch and recovery complex, a flight operation control center, and a cryogenic plant.
Texas Spaceport	TBD	State of Texas Spaceport Authority	No infrastructure at this time.	The final Texas Spaceport site(s) has not been selected yet.
Utah Spaceport	Wah Wah Valley, Utah	Utah Spaceport Corporation	No infrastructure at this time.	Plans for the proposed Utah Spaceport include a central administrative control facility, an airfield, a maintenance and integration facility for both payloads and craft, launch pads, a flight operation control center, and a propellant storage facility.
Woomera Rocket Range	Woomera, Australia	Woomera Rocket Range/Kistler Woomera	Outdated launch site infrastructure, assembly building, and tracking facility.	Kistler will begin work on new facilities when funding is complete. The Australian government passed the "Space Activities Act of 1998" to regulate and attract commercial space business.

Acronyms

AADC – Alaska Aerospace Development Corporation
AFB – Air Force Base
AST - Associate Administrator for Commercial Space Transportation
ATV – Atmospheric Test Vehicle
CCAFS – Cape Canaveral Air Force Station
CCSI – Center for Commercial Space Infrastructure
CTV – Crew Transfer Vehicle
ELV – Expendable Launch Vehicle
EELV – Evolved Expendable Launch Vehicle
FAA– Federal Aviation Administration
GTO – Geosynchronous Transfer Orbit
ISS – International Space Station
KLC – Kodiak Launch Complex
KSC – Kennedy Space Center
LC – Launch Complex
LEO – Low-Earth Orbit
LOX – Liquid Oxygen
MEDS – Multifunction Electronic Display Subsystem
NASA – National Aeronautics and Space Administration
NGSO – Non-Geostationary Orbit
NRA – NASA Research Announcement
RLV – Reusable Launch Vehicle
SFA – Spaceport Florida Authority
SLI – Space Launch Initiative
SSTO – Single-Stage-to-Orbit
TSTO – Two-Stage-to-Orbit
VAFB – Vandenberg Air Force Base
VCSFA – Virginia Commercial Space Flight Authority
VSFC – Virginia Space Flight Center
X-vehicle – Experimental Vehicle

Endnotes

1 Interview with Bob Davis, CEO, Kelly Space and Technology, December 20, 2000.

2 Interview with Bob Davis, CEO, Kelly Space and Technology, December 20, 2000.

3 Interview with Kistler Aerospace Corporation, January 29, 1999.

4 "Preparations for the K-1 Maiden Flight," IAF-00-V.3.06, October 2000 (http://www.kistleraerospace.com/IAF-V-3.06.pdf).

5 "Kistler Receives NASA Study for Alternate Access to Station," Kistler Aerospace Corporation Press Release, August 24, 2000 (http://www.kistleraerospace.com/082400NASA.html).

6 "Space Operations International Signs MOA with Kistler Aerospace Corporation," Kistler Aerospace Corporation Press Release, April 13, 2000 (http://www.kistleraerospace.com/041300SOI.HTML).

7 "K-1 Small Satellite Missions," SSC00-IV-5, August 2000 (http://www.kistleraerospace.com/UTAHSSCOO-IV-5%20Final.pdf).

8 K-1 Payload User's Guide, May 1999.

9 Interview with Kistler Aerospace Corporation, January 29, 1999.

10 "GenCorp Aerojet Successfully Test Fires K-1 Rocket Engine, Test is Key Milestone Toward Kistler's First Launch," Kistler Aerospace Corporation Press Release, March 12, 1998 (http://www.newspace.com/Industry/Kistler/news/pr/46.html).

11 "Kistler Inks Final Agreement in Nevada," Kistler Aerospace Corporation Press Release, October 26, 1998 (http://www.newspace.com/Industry/Kistler/news/pr/71.html).

12 "Pathfinder," *Space Systems Forecast*, October 1998.

13 Pioneer Rocketplane, *Operations Concept* (http://www.rocketplane.com/OpsConcept.html).

14 Interview with Mitchell Clapp, CEO, Pioneer Rocketplane, January 29, 2001.

15 Interview with Mitchell Clapp, CEO, Pioneer Rocketplane, January 4, 2001.

16 Interview with Richard Stockmans, Business Development Manager, Rotary Rocket Company, January 8, 2001.

17 "Rotary Changes Engines, Lays Off Some Workers," *Space News*, July 5, 1999, p. 10.

18 Rotary Rocket Company, *Revolution to Orbit* (http://www.rotaryrocket.com/index.htm).

19 "Ground Breaking for High Bay/Office Complex at Mojave Site," Rotary Rocket Company Press Release, June 19, 1998 (http://www.rotaryrocket.com/new/980619.html); Interview with Rotary Rocket Corporation, January 29, 1999.

20 "Rotary Rocket Reorganizes to Meet Customer Commitments," Rotary Rocket Company Press Release, June 22, 1999.

21 "Space Access' Launch System Based on Airbreathing Ejector Ramjet," *Aviation Week and Space Technology*, March 30, 1998, pp. 75-77.

22 "Rocket Planes," *Popular Science*, February 1999, pp. 44-45.

23 "Space Access' Launch System Based on Airbreathing Ejector Ramjet," *Aviation Week and Space Technology*, March 30, 1998, pp. 75-77.

24 "Space Access' Launch System Based on Airbreathing Ejector Ramjet," *Aviation Week and Space Technology*, March 30, 1998, pp. 75-77.

25 Interview with Stephen Wurst, SPACE ACCESS®, LLC, January 3, 2001.

26 Interview with Stephen Wurst, SPACE ACCESS®, LLC, January 3, 2001.

27 Interview with Stephen Wurst, SPACE ACCESS®, LLC, January 3, 2001.

28 Zegrahm Space Voyages Brochure (http://www.spacevoyages.com/brochure.html).

29 Zegrahm Space Voyages, *Space Cruiser System Fact Sheet* (http://www.spacevoyages.com/factsheet.html).

30 Interview with Pat Kelly, President, Vela Technology Development, December 19, 2000.

31 "AeroAstro LLC Selected as Space Cruiser® Prime Contractor," Vela Technology Development press release, November 25, 1997 (http://www.spacevoyages.com/press5.html).

32 Interview with David Brandt, X33/VentureStar Business Development, Lockheed Martin, January 5, 2001.

33 "Despite Problems, X-33 Demonstrator Remains on Track, Officials Say," *Satellite Today*, September 30, 1999 (www.phillips.com).

34 "RLV Plan Would Split Human, Cargo Roles," *Space News*, February 16, 1998, p. 3.

35 Steven J. Isakowitz, *International Reference Guide to Space Launch Systems*, Third Edition, AIAA, 1999, p. 394.

36 "USA Takes Over Another Portion of Space Shuttle Program," *Satellite Today*, October 1, 1999.

37 Testimony of Andrew Allen, United Space Alliance, before the U.S. House of Representatives Subcommittee on Space and Aeronautics, October 21, 1999.

38 "Industry, Government Leaders Outline Future Space Shuttle Upgrades," *Space Business News*, October 27, 1999.

39 Testimony of William Readdy, Deputy Associate Administrator, Office of Space Flight, NASA, before the U.S. House of Representatives Subcommittee on Space and Aeronautics, October 21, 1999.

40 "X-33," *Space Systems Forecast*, October 1998.

41 "NASA, Lockheed Martin Agree on X-33 Plan," VentureStar Press Release, (http://www.venturestar.com/pages/missupd/pressrel/2000/09290001.php).

42 "X-33 Specifications," NASA Marshall Space Flight Center/X-33 website (http://x33.msfc.nasa.gov/x33specs.html).

43 "Twin Engine Tests for X-33 Take Shape in Mississippi," VentureStar Press Release, (http//www.venturestar.com/pages/missupd/pressrel/2000/10240001.php).

44 "X-33 Program Status," Lockheed Martin Press Release, May 26, 1999, (http://www.venturestar.com/pages/missupd/pressrel/1999/05269901.html).

45 "KSC Delivers X-33 Propellant Loading Equipment to California," KSC Press Release, Aug. 24, 1999.

46 "X-34: Reusable Launch Vehicle Technology Demonstrator," Orbital Sciences Corporation Brochure, 1999.

47 "NASA's X-34 Experimental Rocket Plane Begins New Pre-Flight Test Series," NASA Marshall Space Flight Center Press Release, (http://www1.msfc.nasa.gov/NEWSROOM/news/releases/2000/00-23-.html).

48 "Experimental X-34 Rocket Plane To Begin Extensive Testing," NASA Headquarters Press Release, August 24, 1999.

49 Orbital Sciences Corporation, "Orbital's X-34 Launch Vehicle," (http://www.orbital.com/Prods_n_Servs/Products/LaunchSystems/X34/index.html).

50 "X-34 Gets Boost With Engine Contract," *Space.com*, August 9, 1999 (http://www.space.com/businesstechnology/business/summa_x34_809.html).

51 "NASA Revamps X-34 Testing, Adds Third Test Flight Vehicle," *Aviation Week and Space Technology*, August 30, 1999.

52 "X-34 Program Resumes Tests," *Spaceviews*, July 31, 2000 (http://www.spaceviews.com/2000/07/26b.html).

53 Art Stephenson, NASA Marshall Space Flight Center, Prepared Remarks, FAA Third Annual Commercial Space Launch Forecast Conference, Arlington, VA, February 8, 2000.

54 "X-Prize Foundation Offers Sweepstakes for Space Ride," *St. Louis Post-Dispatch*, May 21, 1998, p. A7.

55 "X Prize Competitor Successfully Launches Two-Stage Rocket," X Prize Foundation Press Release, July 6, 2000.

56 Interview with Gregg Maryniak, Executive Director, X Prize Foundation, January 3, 2001.

57 Scaled Composites, "Proteus Technical Sheet," 1998.

58 Virginia Space Flight Center website (http://www.va-spaceflightcenter.org).

59 "Launch Site Construction Complete," VentureStar Press Release, (http://www.venturestar.com/pages/missupd/pressrel/1999/01219901.html).

60 *The Future Management and Use of the U.S. Space Launch Bases and Ranges*, Report of the Interagency Working Group, February 8, 2000, p. 6.

61 Interview with Dr. Joe Holland, Kelly Space and Technology, 1999.

62 Rotary Rocket website, (http://www.rotaryrocket.com/new/html).

63 Jane's Space Directory, Fifteenth edition, 1999-2000.

64 "Kistler Pursues Funds to Restart Program", *Aviation Week and Space Technology*, December 13, 1999.