Suborbital Reusable Launch Vehicles and Emerging Markets

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About the Office of Commercial Space Transportation

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

Table of Contents

Introduction

Suborbital launch activity has long been overlooked by the commercial market, which for many years focused exclusively on launching satellites. Suborbital launch operations remained primarily in the government sector, supporting missile tests and scientific work, and even there activity declined significantly after the end of the Cold War. Recently, however, there has been a resurgence of interest in commercial suborbital spaceflight, stimulated by the emergence of new markets, notably space tourism, and new vehicles developed by entrepreneurs. With the successful claiming of the Ansari X Prize, high public interest in space travel, and new vehicles under construction, entrepreneurial ventures are pushing a new industry forward at a rapid pace.

The Suborbital Reusable Launch Vehicles (SRLV) and Emerging Markets report provides the first comprehensive assessment by the Federal Aviation Administration's Office of Commercial Space Transportation (FAA/AST) of the commercial suborbital reusable launch industry in the United States. This document reviews three key areas in this commercial suborbital renaissance: new markets for suborbital spaceflight, companies that are developing vehicles to serve those markets, and spaceports from which these vehicles can operate. This report also discusses the recent developments in commercial suborbital spaceflight and the history of suborbital rocketry.

Markets

One of the biggest challenges for the commercial suborbital launch industry-arguably bigger than developing the launch vehicles themselves-has been identifying and developing markets that can be served by suborbital vehicles. The commercial orbital launch industry has the benefit of a major, well-defined market: launching spacecraft to serve telecommunications, remote sensing, and other applications for commercial, civil government and military clients. By contrast, although there is a government market for expendable suborbital launch services, what exists is mostly confined to missile defense and scientific applications that have little commercial applicability.

After initially pursuing the orbital satellite market for low Earth orbit (LEO) constellations in the mid-and late-1990s which has since collapsed, several launch companies have switched to pursuit of suborbital vehicles in a new market: public space travel and space tourism. New companies have also started attracting investors in the past four years. Much of the interest in suborbital space tourism has been galvanized by the Ansari X Prize, a $10-million award offered to the builders of the first privately-developed reusable suborbital vehicle capable of carrying three people to 100 kilometers (62 miles) altitude twice within two weeks. The prize requirements were formulated to create vehicles that serve the space tourism market after winning the prize. In addition, market surveys have shown considerable interest in suborbital spaceflight by members of the public, including those able to afford ticket prices of around $100,000 to $200,000 per flight.

SRLV Proponents anticpate more markets than space tourism. Vehicles that can fly to altitudes of 100 kilometers or more can serve commercial, civil, or military remote sensing markets, filling a niche between aircraft and orbiting spacecraft. The flight profiles of such vehicles will result in several continuous minutes of microgravity, far longer than can be created with aircraft like NASA's KC-135 "Vomit Comet," or its C-9 replacement, which would permit extended microgravity science applications as well as the qualification of experiments intended for flight on the International Space Station. Suborbital vehicles can also serve as the first stage of an orbital launch system, carrying an expendable upper stage that could place small spacecraft into orbit at potentially far lower costs than existing expendable launch vehicles. Other markets include: advertising, hardware qualification, remote sensing, and space diving.

Should some or all of these initial suborbital markets prove viable, the resulting income will provide vehicle developers and operators with a cash flow that will enable the development of new generations of more capable reusable suborbital vehicles. These vehicles, capable of flying to higher altitudes or longer distances downrange, can in turn open new suborbital markets, including rapid delivery of critical packages and, eventually, high-speed passenger transportation. However, these markets may take decades to fully develop, as they require not just new suborbital vehicles but improvements in the overall transportation infrastructure.

Vehicles

Suborbital launches predate their orbital counterparts by decades-centuries if one considers early rocketry experimentation in Europe and Asia. Existing expendable suborbital rockets can trace their heritage back to the efforts of Robert Goddard and Wernher von Braun in the 1920s and 1930s. The early rockets were primarily sponsored for the development missiles rather than space launch vehicles. After the second world war their uses were expanded and they became the forerunners of both orbital and suborbital launch vehicles in use today.

The new generation of commercial suborbital vehicles under development today bears little resemblance to its predecessors. Most of these new vehicles were designed to be eligible for the Ansari X Prize, and thus are designed to safely carry three people and be reusable. Beyond that, however, there were few design restrictions for the prize, and thus there has been an array of different designs put forward. Vehicles under development include those that launch vertically and horizontally, as well as those deployed from aircraft or balloons. Landing systems include a combination of wings, jets, rockets, and parachutes. A variety of other unique design features were also employed to permit the development of reusable suborbital vehicles that could meet the requirements of the prize.

Because many of these vehicles are still in the early development and test stages, it is not clear yet what vehicle designs will prove optimal to serve commercial suborbital markets. It's quite possible that different vehicles will emerge to serve different markets, depending on the unique requirements of those markets and their commercial potential. Vehicle developers are also considering future generations of piloted reusable suborbital spacecraft, including those with increased passenger or cargo capacity, higher peak altitudes, increased time in microgravity, and lower operating costs. In addition, standards for payloads will be important (e.g. vehicle interfaces) for suborbital payloads so as to reduce customer dependence on a single launch services provider. This should have the effect of reducing the risk of scheduling problems, while fostering competition. Historically, one of the enabling elements for new markets and for market expansion has been the development of common industry-wide standards.

Spaceports

The United States currently has 10 commercial and federal spaceports. These facilities, however, are designed primarily to support orbital launch activity, as well as a limited number of conventional, non-commercial suborbital launches. The established federal ranges are less well suited, however, to support launch activities by the emerging generation of piloted reusable suborbital vehicles. These vehicles often do not require the launch pads or range infrastructure of orbital launch vehicles: many need little more than a flat pad or runway, as well as fairly modest tracking capabilities. Moreover, industry is concerned about the cost and regulatory burdens of federal launch ranges and co-located spaceports, due to suborbital vehicle operators' desire to fly on flexible schedules and minimize their range fees. In the opinion of some potential operators range fees would account for the dominant portion of their operations costs.[1]

To address the needs of suborbital vehicle operators, several new spaceports specifically designed to support commercial suborbital launch activities have been or are currently being developed. Mojave Airport in California is the latest facility to obtain an FAA/AST launch site operator license, in June 2004, specifically to serve suborbital vehicles that take off and land horizontally. Other spaceports in New Mexico, Oklahoma, and Texas, are continuing to develop and are seeking FAA/AST spaceport licenses in addition to those already licensed in California (at Vandenberg Air Force Base), Florida, Virginia, and Alaska. New Mexico was selected to host the X Prize Cup, an exhibition and competition of suborbital vehicles, scheduled to start in 2006.

Recent Events in Commercial Suborbital Spaceflight

2003

April 9: Starchaser Industries of Cheshire, England, test-fired its Churchill Mk 2 bi-propellant engine for the first time. The engine will be used on the company's Thunderbird and Thunderstar suborbital RLV vehicles.

April 16: XCOR Aerospace of Mojave, California, announced $187,500 in additional equity investments. The investments qualify the company for a Defense Department program that matches private capital four to one. The company will use the investment to develop rocket pump technology for its planned suborbital RLV.

April 18: Scaled Composites of Mojave, California, unveiled its "Tier One" suborbital spaceflight program, consisting of an aircraft, White Knight, which carries aloft a rocket-powered spacecraft, SpaceShipOne.

May 20: Scaled Composites flew the first captive carry flight of SpaceShipOne and White Knight from the Mojave Airport in California.

June 26: Canadian Arrow of London, Ontario, announced its team of six astronauts - four Canadian, one American, and one Ukrainian - who will fly the company's eponymous suborbital RLV.

July 5: Armadillo Aerospace of Mesquite, Texas, performed a drop test of a prototype of its Black Armadillo vehicle to test parachute deployment and its crushable nose cone.

July 22: Starchaser Industries conducted a drop test of its Nova 2 capsule, part of its Thunderbird suborbital RLV, at Red Lake, Arizona.

August 7: Scaled Composites flew the first glide test of SpaceShipOne, detaching from the White Knight carrier aircraft at an altitude of 14,320 meters (47,000 feet) and gliding to a landing at the Mojave Airport 19 minutes later.

October 20: The FAA published a notice in the Federal Register officially defining suborbital rockets and suborbital trajectories and stating that vehicles that meet these definitions will be regulated by AST.

October 28: The da Vinci Project of Toronto, Ontario, announced that it will perform the X Prize qualification flights of its Wild Fire suborbital RLV from Kindersley, Saskatchewan.

October 30: FAA/AST determined that XCOR Aerospace's launch license application for a manned suborbital RLV was sufficiently complete.

November 22: High Altitude Research Corporation (HARC) of Huntsville, Alabama, unveiled its Liberator suborbital RLV project.

December 15: The X Prize adds two teams to its competition: HARC and Space Transport Corporation of Forks, Washington.

December 17: On the centennial of the Wright Brothers' first airplane flight, Scaled Composites conducted the first powered flight of SpaceShipOne, achieving a top speed of Mach 1.2 and peak altitude of 20,720 meters (68,000 feet). The company also announced that Microsoft co-founder Paul Allen has been the financial sponsor of the project.

2004

January 12: Rocketplane Ltd. (formerly Pioneer Rocketplane) announced that it had broken ground on facilities at the Oklahoma Spaceport in Burns Flat, Oklahoma. Those facilities will be used to build and operate its planned suborbital RLV.

January 21: The X Prize Foundation selected Florida and New Mexico as finalists to host the X Prize Cup, a competition among suborbital RLV companies.

February 4: The House Science Committee approved by voice vote H.R. 3752, the Commercial Space Launch Amendments Act of 2004. The legislation specifically identifies AST as the regulating authority for suborbital spaceflight, establishes an experimental permit system for RLVs, and extends the existing liability regime to cover commercial RLV flights, including those carrying passengers.

March 4: The House of Representatives approved H.R. 3752 on a vote of 402-1.

March 28: Space Transport Corporation successfully test-fired its 53,400-newton (12,000-pounds-force) solid-propellant engine that will power the company's suborbital RLV.

April 1: FAA/AST awarded a launch license to Scaled Composites for SpaceShipOne, the first manned suborbital launch license issued by the agency.

April 8: Scaled Composites conducted the second powered flight of SpaceShipOne, achieving a top speed of Mach 1.6 and peak altitude of 32,000 meters (105,000 feet).

April 23: FAA/AST awarded a launch license to XCOR Aerospace for its Sphinx manned suborbital RLV.

May 5: The X Prize announced a multimillion-dollar donation from entrepreneurs Anousheh Ansari and Amir Ansari. The prize was renamed the Ansari X Prize.

May 11: The X Prize Foundation selected New Mexico as the state where the annual X Prize Cup, a series of flight competitions for suborbital vehicles, expected to begin in 2006, will be held.

May 17: GoFast, a suborbital rocket built by the amateur Civilian Space Exploration Team, achieved a maximum altitude of 124 kilometers (77 miles) in a launch from the Black Rock Desert, Nevada. The launch was the first time an amateur-built rocket reached space.

June 15: Armadillo Aerospace conducted a successful test flight of its subscale technology demonstrator vehicle in Mesquite, Texas, achieving a maximum altitude of 40 meters (131 feet).

June 17: FAA/AST awarded a launch site operator license to the East Kern Airport District to cover suborbital spaceflight activities at Mojave Airport.

June 21: Scaled Composites conducted the third powered flight of SpaceShipOne, achieving a maximum speed of Mach 2.9 and a peak altitude of 100,124 meters (328,491 feet). The flight was the first time a commercial manned suborbital spacecraft reached space. The pilot, Michael Melvill, was awarded FAA/AST commercial astronaut wings.

June 23: Starchaser Industries announced it would open a U.S. office in Las Cruces, New Mexico, with plans to begin flight operations from the Southwest Regional Spaceport as early as 2006.

July 22: The Space Commercial Human Ascent Serving Expeditions (CHASE) Act, S.2722, the Senate version of H.R. 3752, was introduced.

July 27: Mojave Aerospace Ventures (the official name of the Ansari X Prize team led by Scaled Composites and funded by Paul Allen) announced that it would conduct the first of its two planned Ansari X Prize qualification flights on September 29 from Mojave, California.

August 5: The da Vinci Project announced that it would conduct the first of its two planned Ansari X Prize qualification flights on October 2 from Kindersley, Saskatchewan.

August 7: A subscale technology demonstration vehicle built by Armadillo Aerospace crashed during a test flight in Mesquite, Texas, when the vehicle ran out of propellant at an altitude of approximately 180 meters (600 feet).

August 8: Space Transport Corporation's Rubicon 1 vehicle was destroyed during a test flight near Queets, Washington, when one of the vehicle's two solid fuel motors exploded on ignition.

August 14: Canadian Arrow conducted a successful drop test of its passenger capsule, dropping it 2,400 meters (7,900 feet) from a helicopter into Lake Ontario near Toronto.

August 16: Masten Space Systems, of Santa Clara, California, announced that it planned to develop the XA-1, a reusable unmanned suborbital vehicle capable of flying to 100 km altitude to serve microgravity and other research and development markets.

August 17: The da Vinci Project announced it had changed its name to "The GoldenPalace.com Space Project: Powered by the da Vinci Project."

September 23: The GoldenPalace.com Space Project: Powered by the da Vinci Project announced that its planned October 2 launch from Kindersley, Saskatchewan, would be delayed for an unspecified period because of delays in the availability of a few key components.

September 25: Beyond-Earth Enterprises of Colorado Springs, Colorado, conducted two flight tests of one-third scale demonstrators of its planned recoverable suborbital rocket from Frederick, Oklahoma; one rocket reached an altitude of over 4,575 meters (15,000 feet).

September 29: SpaceShipOne, piloted by Mike Melvill, completed the first of its two Ansari X Prize qualification flights at Mojave Airport, reaching a peak altitude of 102,870 meters (337,500 feet). The prize judging team declared the flight a successful attempt the following day.

October 1: The GoldenPalace.com Space Project: Powered by the da Vinci Project announced that Transport Canada, the Canadian equivalent of the U.S. Department of Transportation, had awarded the team a launch license for its Wild Fire vehicle. The license expired on November 1, 2004.

October 4: Rocketplane Ltd. announced that it had entered into an agreement with tourism company Incredible Adventures, of Sarasota, Florida, to market tourist flights on Rocketplane's XP vehicle starting in 2007, at a ticket price of $99,500.

October 4: SpaceShipOne, piloted by Brian Binnie, completed the second of its two Ansari X Prize qualification flights at Mojave Airport, reaching a peak altitude of 112,000 meters (367,442 feet). The prize judging team declared the flight a success the same day, and officially declared Mojave Aerospace Ventures, sponsors of the SpaceShipOne team, the winners of the prize.

November 6: Mojave Aerospace Ventures was presented with a check for $10 million dollars and a trophy for capturing the Ansari X Prize in a ceremony at the St. Louis Science Center in St. Louis, Missouri.

November 20: U.S. House of Representative passed H.R. 5382, a revision of H.R. 3752 by a vote of 269 to 120. H.R. 5382 addressed concerns about language definining what types of vehicles are considered as suborbital, crew safety and passengers rights to sue operators.

December 9: U.S. Senate passes H.R. 5382 by a unanimous vote.

Suborbital Markets - An Overview

Expendable suborbital vehicles have been serving several distinct markets for over 40 years. However, the suborbital field has seen many changes during that time. The use of suborbital vehicles, including sounding rockets, has dropped considerably since the Cold War period, when several hundred such vehicles were launched annually. Suborbital vehicles were then used predominantly for military and scientific research funded almost entirely through government budget allocations. Universities were also major participants in sounding rocket programs, a relationship enabled by public funding in the form of research grants. However, the number of Ph.D. theses dedicated to atmospheric or astronomical research dependent on sounding rockets has continually declined since the 1970s.

During the suborbital heyday of the Cold War, it was not uncommon for more than 700 suborbital rockets to be launched annually to serve the military and scientific markets. Even in the late 1980s the average number of suborbital rockets launched for military, scientific, and educational purposes remained over 300 annually. A significant decrease in the early 1990s, however, has left the annual market for suborbital launches at well under 100. This decrease in demand for suborbital launches has many causes, but three factors appear as the most significant. First, with the collapse of the Soviet Union in 1991 and the end of the Cold War, the number of military suborbital research and missile test launches has dropped. Second, students pursuing graduate research appear less likely to do so in fields requiring sounding rockets, instead focusing on genetics, microbiology, computer engineering, and other disciplines. Finally, traditional users of suborbital vehicle technology are increasingly turning to other options, such as computer simulations, stratospheric balloons, and high-altitude aircraft, to perform their research.

There are, however, a few signs that the number of expendable suborbital vehicles launched annually will increase in the near future. For example, the Department of Defense (DoD) will continue to launch interceptor and target vehicles in support of an anti-ballistic missile shield. Another positive sign is the growing number of rocket hobbyists and enthusiasts interested in building and launching rockets. These rockets have become more powerful, and it is possible that a handful of these rocket amateurs may pursue business plans based on successful vehicle performance.

Reusable suborbital vehicles, on the other hand, are expected to lead a renaissance in the suborbital marketplace, beginning with human suborbital adventure travel. While the idea of a human-rated vehicle capable of suborbital missions is not new, the potential for a commercial suborbital industry is. Recent studies have demonstrated that customer demand for suborbital adventure travel is robust enough to get an industry rolling, and it is expected that the winning of the Ansari X Prize will effectively initiate this emerging market.

Other short-term commercial suborbital markets that may emerge in the next ten years include science and high-speed research, microsatellite insertion, microgravity research, hardware qualification, military and commercial remote sensing, and advertising and sponsorship. Still more markets are expected to emerge 30-40 years from now, when second- and third-generation vehicles allow for point-to-point travel and are supported by more extensive ground infrastructure.

SRLV Emerging Markets

Tourism and Adventure Travel

Space tourism and adventure travel is likely to become the first successful suborbital market to emerge during the next ten years. The birth of this market is expected to begin around 2007, spurred in large part by the emergence of suborbital vehicle entrepreneurs outside the aerospace industry mainstream and competitive pursuit of the Ansari X Prize, which was won in October 2004. The X Prize Foundation was established in 1996 to award $10 million to the first team to launch a suborbital reusable launch vehicle (SRLV) capable of carrying three people to an altitude of 100 kilometers, return safely to Earth, and repeat the exercise within two weeks. With patronage from the Ansari family, the renamed competition produced a group of 20 plus domestic and international contenders and symbolizes the introduction of a truly reusable passenger-carrying space launch vehicle. Even though the Ansari X Prize has been won, SRLV development and testing by the various teams is expected to continue in pursuit of recognition, business ambitions and other prize competitions. The Foundation will sponsor special events around the world similar in principle to air shows, designed to promote nascent suborbital markets and provide competitions to keep innovation thriving. The X Prize Foundation is attempting to create a new business model for space business to include sponsorships.

To follow-on the successful X Prize, the X Prize Cup has been announced. The Cup will feature a series of cash prize competitions ranging from fastest turn-around time, maximum number of passengers per flight and during the entire Cup event, to maximum altitude attained and fastest flight time from take-off to landing. An overall annual X Prize Cup title will also be awarded based on points in the other competitions. Flight competitions for the X Prize Cup are scheduled for October 2006. A Public Spaceflight Exhibition is planned for October 2005. Both Cup-related events will be held in New Mexico.

Unlike the commercial satellite launch market - the focus market of initial RLV entrepreneurs- the demand for tourism flights is expected to be significant in the coming years. Tourism companies involved with marketing space travel, including Space Adventures, Ltd, Incredible Adventures, and Virgin Galactic, have described a high level of fascination and interest from the public. After Mojave Aerospace Ventures won the Ansari X Prize, Virgin Galactic alone reported that 7,000 people had registered for future tourist flights on a vehicle based on SpaceShipOne to be built by Scaled Composites.

Futron Corporation produced a comprehensive report[2] of space tourism and adventure travel in 2002. Futron contracted with Zogby International to survey 450 individuals with annual incomes of at least $250,000 or a net worth of at least $1 million. The study identified realistic price points: between $25,000 and $250,000 per suborbital flight, and $1 million to $25 million per orbital flight. A former Space Shuttle commander with substantial experience in human spaceflight helped to draft a description of what a realistic space experience would be like for a private citizen.

The responses gathered from the 450 surveyed individuals were analyzed over a period of eight months, and profiles of those who were most likely to pay for a space experience were developed. Some 42 percent of the respondents characterized themselves as either “somewhat likely,” “very likely,” or “definitely likely” to pay for a suborbital ride, and 51 percent of those indicated they would pay at least $25,000 for the privilege. Customer preferences were identified for the basic trip scenarios and compared with the realistic description of a trip to space.

The analysis, which resulted in a 20-year forecast of passengers and revenue, did not address the business case for a suborbital vehicle; rather, it addressed the demand for services that might be provided via a suborbital or orbital vehicle. The

Table 1: Announced Suborbital Space Tourism Agreements

Vehicle Operator	Vehicle Name	Tourism Marketing Company*	Estimated First Operations Flight	Advertised Price Per Passenger	Passengers Per Flight	Passengers Registered for Future Flights**	Launch Site
Mojave Aerospace Ventures, LLC	SpaceShipTwo	Virgin Galactic	2007	$190,000	5	7,000	Mojave Airport, California
Rocketplane Ltd	Rocketplane XP	Incredible Adventures	2007	$99,500	2	Unannounced	Burns Flat, Oklahoma
XCOR Aerospace	Xerus	Space Adventures	2007	$98,000	1	Unannounced	Mojave Airport, California

*Some operators have more than one marketing company.
**Space Adventures has reported over 100 deposits for space flights for vehicles to be determined.

challenge for the aerospace industry is to develop a vehicle that can most effectively meet this demand.

Results of the study showed that demand for suborbital space adventure travel exists, and that it remains latent because of a lack of vehicles. Once vehicles are introduced (and the assumption for purposes of the study was that such vehicles could carry two passengers), the study forecast that a total of almost 16,500 people could be traveling to suborbital altitudes by the year 2021. Those passengers would pay suborbital vehicle operators fares that, combined, would total an estimated $800 million in revenues.

It should be noted that this study focused on suborbital and orbital passenger flights, and did not address demand for other services in detail. In addition, the scope for the study did not focus on the support infrastructure necessary to sustain the projected number of flights. It is possible that additional, perhaps more significant, sources of revenue resulting from suborbital activity will emerge. Additional space tourism studies have been done by Space Adventures, NASA, National Space Society, and Patrick Collins among others.

Science and High-Speed Research

Not long after rockets were invented, it became clear that instruments for measuring the upper atmosphere, imaging the Sun, and otherwise studying the environment many hundreds of kilometers above the Earth could be installed as payloads. In the earliest cases, data was retrieved on tapes that returned to Earth after a short flight. Often the data was destroyed, but sometimes it returned intact and revealed information about the ionosphere and the Sun's corona. Launching specialized suborbital rockets (sounding rockets are so named because they have been primarily limited to atmospheric research,) has continued to this day, but at a much reduced level.

Since 1989, the FAA has licensed 14 suborbital launches by expendable vehicles, all connected to government sponsors. For most universities with interest in flying space science experiments and satellites, cost is the primary issue. Launches have been difficult to fund without government support: some universities build complete satellites with no budget to actually launch them. Principal investigators funded by NASA are unable to select their own commercial launch services because their experiment funding includes money to launch on government-built suborbital vehicles, typically from Wallops Flight Facility in Virginia. This has led to U.S. government control of the vehicle market for civil science payloads.

Because of recent budget cuts to NASA's sounding rocket program, fewer launches are expected and scientific review panels are taking fewer risks.[3] The cost of launching solar and astrophysics missions requiring higher performance vehicles and recoverable payloads from White Sands Missile Range is no longer affordable.[4]

New, reusable suborbital launch vehicle firms believe they can offer more frequent flight opportunities at similar or lower costs than NASA if science investigators were given funding vouchers for selecting their own launch vehicles.

A small but proven international commercial market for expendable suborbital vehicles has been a high-speed test bed for scientific experiments. Australia's University of Queensland flew two supersonic combustion ramjet (scramjet) test missions called Hyshot from Woomera, Australia, on Astrotech's Terrier-Orion vehicles. Even though the launch was not conducted for or by the U.S. government, the Terrier-Orion vehicle was built by an American company, Astrotech and therefore these missions were licensed by the FAA. The 2001 and 2002 flights will be repeated with future missions by DTI (formerly Astrotech), possibly in 2005.

Other countries have emerged as major providers of suborbital launch services, including Norway, Japan, Brazil, and India. No particular country dominates the field of suborbital high-altitude research.

SRLVs may introduce a resurgence in suborbital high-altitude research, perhaps akin to the phenomenally successful joint NASA-Air Force X-15 vehicle flights of the 1960s. One advantage of the X-15, beyond its high speed, was the ability to change out instrument racks quickly and efficiently, reducing turn-around time in order to accommodate researchers' schedules. Such an approach would be ideal for a commercial vehicle used for research and other purposes. In addition, a single SRLV can be used to monitor the Earth's upper atmosphere over the span of many years at potentially a much lower total cost than to conduct the same research using many expendable rockets.

Microsatellite Orbital Insertion

Suborbital vehicles can be designed as a first stage for launching small satellites into LEO. Essentially, a piloted SRLV would reach a specific altitude determined by such parameters as orbit desired, atmospheric conditions, and mass of the payload, and then release an upper stage with the payload attached. The upper stage - in much the same way an upper stage would send a satellite to geosynchronous orbit (GEO) after separating from an orbital launch vehicle - would boost the small satellite to the required orbit. The SRLV would then coast back to a landing site, either powered or unpowered depending on the design.

A similar concept already being pursued by the Defense Advanced Research Projects Agency (DARPA) is called RASCAL, or Responsive Access, Small Cargo, Affordable Launch. RASCAL will be composed of an air-breathing first stage capable of reaching 61 kilometers (200,000 ft) altitude while carrying a small upper stage. The complete system will be capable of deploying 50 kilogram (110 pound) microsatellites directly into orbits with any inclination. The RASCAL vehicle will be able to take off within one hour of a launch command and refly again within 24 hours at a cost of no more than $750,000 per flight. The program has progressed past the Preliminary Design Review stage due to the efforts of the Space Launch Corporation contractor team. Phase 3 development is scheduled to begin during 1st quarter of 2005. During Phase 3 prototype vehicles will be construted. The first satellite launches are expected to occur in 2008.[5]

The market for microsatellites is not well understood, but enough data exists to indicate that at least two customer groups would be interested in a very low-cost method of launching "throwaway" microsatellites. One Stop Satellite Solutions (OSSS), based in Utah, builds microsatellites primarily for university clients. According to OSSS, several of their satellites remain on the shelves because universities simply cannot afford the launch costs. The satellite may cost as little as a few thousand dollars, but the launch is orders of magnitude more expensive. If a vehicle could launch them at lower costs, OSSS foresees thousands of its satellites being launched annually in twenty years.

Similarly, agencies like DARPA have an interest in studying technologies related to microsatellites, including constellations of maneuverable mini-spacecraft. Some high technology research and development efforts end without achieving actual space testing. If the price tag of such projects could be reduced by utilizing inexpensive launch options, more money could be spent on satellites and related technologies.

Microgravity Research

SRLVs may participate in and stimulate microgravity research. While suborbital RLVs cannot match the extended microgravity research possible in orbit, more experiments can be sent up than might be otherwise possible for customers waiting for orbital flights with a faster turnaround. SRLVs can also allow researchers greater flexibility at lower costs than for researchers who must depend on the occasional orbital launch that costs hundreds of millions of dollars. For example, physiological research could be conducted on a routine basis, a particularly useful scenario if the vehicle can maneuver (as opposed to a ballistic vehicle whose maneuverability is relatively limited). Indeed, the researcher himself or herself can go along for the ride on a SRLV, rather than depend on a professional astronaut who must be trained.

Media, Advertising, and Sponsorship

Entertainment media outlets, advertising agencies, and sponsorship by a wide variety of interested parties is expected to show interest in new suborbital launch vehicles. While these groups will not necessarily purchase a launch, they will provide an important source of revenue for SRLV operators. In addition, it is probable that there will be an initial spike of interest among these groups to exploit the "newness" of SRLV technologies, followed by a gradual flattening out as the overall market matures. Feature and documentary filmmakers may have an interest in pursuing new opportunities presented by access to space on suborbital vehicles. The Discovery Channel paid for rights to telecast two documentaries about the Ansari X Prize in October 2004. Similarly, access to Russian submersibles, previously unavailable to the commercial sector, allowed filmmaker James Cameron to visit the sunken Titanic up close for the movie "Titanic" and documentary "Ghosts of the Abyss." Realistic microgravity scenes in "Apollo 13" were filmed aboard a modified KC-135 ("Vomit Comet") airplane, which has since been turned into a commercial business by the Zero-Gravity Corporation. Commercial SRLV operators may provide a new outlet for visual entertainment in the decades ahead.

Advertising is a tried-and-true method of selling products and ideas. Commercial SRLVs, and even non-commercial ones, will likely be emblazoned with the livery of the manufacturers and sponsors in the same tradition we see today with orbital launch vehicles. It is rare that a third party will pay for the privilege to advertise on a launch vehicle, but it has been done. Pizza Hut, in one famous example, paid to have its logo pasted to the side of a Russian Proton vehicle. During the final Ansari X Prize qualifying flight SpaceShipOne featured the Virgin Group logo on its fuselage.

Advertising could also come from companies who provided subcomponents, engineering, design, and other services for the prime contractor or SRLV operator. Other opportunities exist for non-profit organizations and political campaigns. SRLVs present a unique opportunity for advertisers not only because of their novelty, but also because SRLVs represent an opportunity to link the once-distant idea of space with the average consumer. Media exposure also makes SRLV advertising attractive to potential advertisers.

Finally, sponsorship, which has a long history in jump-starting nascent markets, will have a role to play as the emerging SRLV industry gains a foothold. Sponsorship can come in a variety of forms, including sending people into space as a result of winning a lottery or prize paid for by the sponsor, or providing astronauts and passengers with jumpsuits covered in patches representing donor organizations (similar to the suits worn by NASCAR drivers). Another opportunity already exploited in orbit is granting astronauts the right to utilize a product in space in exchange for the novelty of simply seeing the product used in space.

Public sponsorship through the collection of monies from interested organizations and individuals to create prizes to be awarded for a variety of contests related to SRLVs, such as the Ansari X Prize and the X Prize Cup will perhaps profoundly affect the development of SRLVs. Contests take advantage of the competitive streak in human beings and promote creativity, innovation, and teamwork, often across traditional political barriers. These contests by necessity break through stagnant thinking and the status quo, which is why they are effective in jump-starting emerging markets.

Prizes sponsored by companies and wealthy investors were awarded for a variety of aviation firsts and were key motivators in sparking what has become the commercial aviation industry today. Prizes often promote more spending than the amount of the purse. They allow the promoter to advance his goal without choosing a technology or a vehicle. Development of the required technology often continues after the reward has been claimed. An historical example of this is the Vin Fiz-sponsored cross country flight in 1911, in which Cal Rogers flew a Wright Flyer from Long Island to Long Beach in pursuit of the Hearst Prize. Publisher William Randolph Hearst offered a $50,000 prize to the first aviator to cross the country in 30 days or less. Rogers took 84 days, 16 stops and endured 19 crashes during the flight, but kept going even after it was clear he could not win the prize. In a more recent example, Canada's Da Vinci Project, Canadian Arrow, America's Armadillo Aerospace and others have continued development of their vehicles, even though Mojave Aerospace Ventures has already won the Ansari X Prize.

Hardware Qualification

Another potential use of SRLVs would be to subject equipment to the launch and microgravity environment prior to certification on manned space platforms like the International Space Station. However, this market would compete with cheaper testing methods currently available such as aircraft and ground-based load-testing facilities. Furthermore, the loads offered by the piloted vehicles currently in development might only be attractive to equipment developers intending their hardware for transport and use aboard manned space vehicles. Unmanned rockets subject equipment to sounds, loads, and vibrations in excess of human tolerances. Aircraft offer about 30 seconds of microgravity during the arcing flight paths they use to generate microgravity conditions. The current generation of SRLVs while offering several minutes of microgravity, are not envisioned to conduct aircraft style flight profiles. SRLV operators would have to develop a method to repeat or extend the microgravity times during a single flight in order to offer a competing experience to hardware developers. The aircraft in current use also offer more volume for experimentation. While no SRLVs are currently being offered with similar accommodations, as the designs mature larger vehicles may appear. However, it is conceivable that if an equipment item is small enough to share a flight with other cargo or passengers then cost might become low enough to make SRLVs a viable alternative to established methods of manned flight hardware qualifications.

Commercial Remote Sensing

The remote sensing industry consists of four main parts: aerial imagery, ground stations, value-added products (often called geographic information systems, or GIS), and satellites. Total sales for all sectors of the U.S. remote sensing industry amounted to an estimated $2 billion in 2001, with the bulk attributable to the sales of GIS software and services and aerial imagery. Worldwide sales of raw commercial satellite remote sensing imagery generated an estimated $200 million in revenues for 2001, with a projected revenue total approaching $500 million by 2010.

Typical platforms (aircraft and satellites) host a suite of passive sensors designed to detect reflected light and include panchromatic (visible imagery, such as that produced by a camera) and infrared (IR) sensors. Active sensors providing radar and lidar imagery are also examples of services offered by aerial and satellite remote sensing providers. While aerial imagery is obtained relatively close to the Earth, yielding high-resolution imagery and real-time data across a broad spectrum, the services provided are expensive. In addition, legal and international restrictions prevent aircraft from flying over selected territories. Remote sensing satellites, in contrast, orbit high above the Earth providing essentially the same types of services at less expensive rates relative to aerial methods, though generally with a slightly degraded resolution (this is rapidly changing, however). Also, real-time commercial satellite remote sensing products are not yet available. Some emerging SRLV businesses have recognized a “gap” between altitudes exploited by aerial platforms and those occupied by LEO satellites. This niche, the suborbital remote sensing realm, may prove useful for some clients interested in high-resolution, quick-turnaround imagery covering a larger area than an aircraft could. A satellite could cover the same area, but its orbit may not traverse the area of interest for several days.

Potential clients include disaster relief agencies, insurance companies, oil companies, international banks, meteorologists, and military organizations. These groups have a strong interest in inexpensive, real-time, high-resolution, quick-turnaround remote sensing products. The challenge for commercial SRLV operators will be to keep the cost of operating and maintaining their SRLVs low, so that inexpensive services relative to aerial platforms can be provided. And like aircraft, a SRLV conducting remote sensing flights would need to operate near the target area of interest. The flexibility of operating from multiple locations and local airspace regulations would need to be considered. Some emerging SRLV providers, like TGV Rockets, expect to reap the benefits of this untapped market.

Military Surveillance

Collection of national security imagery is done by both aerial platforms and satellites. Crewed aircraft have been used by the military for almost a century. Uncrewed aerial vehicles (UAVs) are relatively new to modern warfare, with projections showing that many such vehicles will be flying around the war zones of the future. As it is today, these systems cover several “layers” in terms of remote sensing platforms. Satellites adequately cover the ultimate high ground but have limited maneuvering ability, while UAVs and crewed reconnaissance aircraft like the U-2 are deployed within the Earth’s atmosphere and are highly maneuverable.

Suborbital launch vehicle remote sensing systems have been proposed as a method of "filling in" the layer between satellites and aircraft. Such a system is envisioned by TGV Rockets, as a "pop-up" capability giving military leaders a near real-time snapshot (perhaps even video for short periods) of theater-wide operations. TGV plans to offer its mobile platform launched MICHELLE B vehicle for this purpose.[6] The challenge for suborbital systems is to be cost-competitive with other aerial vehicles while offering unique services.

Space Diving

During the late 1950s and early 1960s, the U.S. Navy and the U.S. Air Force conducted manned parachute jumps from high altitude balloons, prior to the first NASA Mercury astronaut suborbital and orbital missions. Joe Kittinger of the United States Air Force, who successfully jumped from an altitude of 31,300 meters (102,800 feet) in 1960, currently holds the world record for a human high-altitude dive.[7] During the 1960s, the National Aeronautics and Space Administration (NASA) researched orbital escape systems for astronauts. Several "space parachutes" were designed featuring maneuvering thrusters, conical drag skirts, inflatable cones, and spray-on ablative shielding to protect a single astronaut during reentry. It was concluded that a self-contained ballistic recovery system could be designed to bring a stranded astronaut safely to the ground.

Recently, there have been plans by some to break Joe Kittinger's 31-kilometer (19 miles) altitude record. Several teams from across the globe are intent on jumping from altitudes of almost 45 kilometers (28 miles). Some of the competitors are: Cheryl Sterns, who will make an attempt from an undisclosed site in the western United States during September 2005; Michel Fournier of France; and Rodd Millner of Australia. These jumps will be conducted using stratospheric balloons. The balloon is the limiting factor for the world record pursuers. The use of an SRLV, which is less reliant on atmospheric conditions, will allow competitors to easily break any previously held altitude records using balloons as platforms.

The Canadian Arrow team, a competitor for the Ansari X Prize, is proposing a new extreme sport called "spacediving."[8] As Canadian Arrow envisions it, future spacedivers could routinely take 60-second suborbital flights, reach apogee, then proceed to jump out while wearing a counter pressure suit, and free fall to Earth from an altitude of 64 kilometers (40 miles) or more. Today, reaching an altitude of 37,000 meters (121,400 feet) to make a high-altitude jump requires a balloon ride of many hours. An SRLV, on the other hand, could take spacedivers from the ground to this altitude in minutes. This sport will likely start with jumps initially at lower altitude; with higher record-breaking jumps following as experience is gained.

Space diving could bring about new advances in spacesuit design. One anticipated development is the counter pressure suit. This type of suit uses elastic material instead of gas pressure to protect an astronaut from the vacuum of space.

A detailed market analysis on the demand for space diving remains to be pursued. According to Christchurch Parachute School in New Zealand,

> *"there are a growing number of people who are trying skydiving in the search for the ultimate leisure activity. Consequently, the skydiving industry is experiencing rapid growth in the adventure tourism market to cater for this need. This demand is creating a whole new industry for people to become involved in and creating many new full-time positions not previously considered as serious career options."*

If leisure skydiving is increasing in popularity, it stands to reason that a small but growing minority will be interested in pushing the envelope ever higher. Skydivers will make excellent suborbital customers, as they understand safety procedures and systems. The adventurous few who have made high-altitude jumps will be familiar with oxygen systems and high-altitude survival.

SRLV Long-Term Markets

Fast Package Delivery

In a typical business as services become more efficient, competition will become fiercer and customers will demand more. Delivering packages is an excellent example of this phenomenon. Consider that before 1973, when Federal Express began operations, people had to wait weeks before packages were delivered. This was mainly because of operational issues rather than the vehicles involved. In 1965, Yale University undergraduate Fred Smith wrote a term paper about passenger route systems used by most airfreight shippers, and concluded that operationally, these routes were being used inefficiently. Smith wrote of the need for shippers to have a system designed specifically for airfreight that could accommodate time-sensitive shipments such as medicines, computer parts, and electronics. Apparently, Smith's paper received an average grade, but the student knew he had an idea that could serve as a business plan. After several years of planning, he founded Federal Express in 1971 and started operations with a small fleet of aircraft in 1973.[9]

The key to success was less about aircraft and more about smart logistics. The subsequent introduction of laser tracking technologies, more efficient long-range aircraft, satellite asset tracking, better management applications, and streamlined collection nodes made FedEx and some of its competitors known and trusted commodities on a global scale. In 2003, FedEx reported total revenue of $22.5 billion,[10] generated through the work of 214,000 employees.[11] Its main competitor, United Parcel Service (UPS), is actually a larger company, having generated about $30 billion in revenues during the past year. UPS was founded in 1907 as a messenger company in the United States, and has grown by focusing on enabling commerce around the globe. Other competitors include DHL and Emery.

It is possible that, if effectively integrated within a larger logistical framework, SRLVs could become a valuable asset for companies like FedEx and UPS. "Effectively integrated" means that the SRLV would operate more or less like an aircraft, and thus not require its own specialized launch pad, exotic fuels, and a high degree of maintenance. These factors alone demonstrate that SRLVs used as fast package deliverers is some time off, since SRLVs have yet to be introduced and proven as reliable, safe, and effective modes of transportation. It was only after aircraft had been used for 60 years that a Federal Express business model became achievable. UPS was founded four years after the Wright brothers' first successful heavier-than-air flight, but the company did not ramp up air operations until it became clear Federal Express was a serious competitor.

Whether a significant market exists for packages to be delivered halfway around the planet within hours remains unclear. It is probable that, in a world faster-paced than the one we live in today, the notion of packages delivered from Tokyo to Paris within several hours will be desired. Perhaps organ donation is a market for charter SRLVs, though advances in biomedical research (such as growing organs) may negate the demand for such extreme transportation services.

Companies will likely not invest in SRLVs unless they can be successfully integrated into their already highly-efficient operations, and this is dependent on the technologies and processes intrinsic to the vehicle itself. If a low-cost vehicle operates in the same manner as an aircraft, it is very likely one will see FedEx and UPS SRLVs at aerospaceports one day in the future. This application is considered far-term because it may take decades for SRLVs to become efficient, reliable, and safe enough to operate within a logistical framework.

High-Speed Aerospace Transportation

High-speed aerospace transportation from one point to another on the surface of the Earth is perhaps the "holy grail" of the suborbital industry. The idea of taking a suborbital flight from New York to Sydney, Australia in two hours has been around for decades, and several attempts to pursue the concept have started enthusiastically only to be shut down when reality sets in. It is very easy to look at a new Boeing 777 or even the older, now-decommissioned Concorde, and extrapolate a near-term future in which special aircraft can travel farther and faster for the same ticket price one might be charged today for first-class service. However, many things must take place for this to become a reality.

Current commercial air travel is hampered by serious logistical problems linked in large part to an adherence to a very old concept involving hub airports and directed flight routes. In a sense very little has changed, other than the aircraft themselves, since the 1930s. As SRLVs must accelerate to hypersonic velocities their use will likely be more effective in long-distance, point-to-point travel. As with fast package delivery, the issue regarding passenger-carrying SRLVs has less to do with technologies and more to do with processes. Changing processes related to a national infrastructure depended upon by millions of people each day is a daunting problem beyond the scope of this report. But efforts are underway to radically rethink how airplanes are operated and how assets are transported. Once these complicated problems are solved, at least partially, then it might become apparent that a need for large passenger-carrying SRLVs exists.

If the new SRLV developers produce a system that can be operated by a profit-making service provider over a sustained period, this could constitute the beginning of high-speed transportation. Travel could go from one spaceport to another or to an existing airport runway. As the distances increase, so do requirements for cross-range maneuvering, fuel storage, and navigation. The design of the vehicle may become bigger, perhaps allowing for the transport of additional people or cargo. Point-to-point travel will become a reality if SRLVs prove to be as operable, maintainable, and safe as passenger and cargo aircraft.

Two major sectors may benefit from SRLVs: Charter service and long-distance transportation of passengers and goods. In the former case, SRLVs could be used for the transport of people and certain types of cargo via transcontinental suborbital routes. For example, transporting key personnel and equipment to disaster zones will require that these assets be deployed as soon as possible. Several hours can make a big difference in many scenarios. The military may be interested in an SRLV for similar reasons, but these vehicles may not be operated by a commercial entity.

Long distance suborbital transportation of passengers and goods is what people imagine as the pinnacle application of suborbital technology. This concept involves a large vehicle capable of taking off from a runway and reaching an altitude of around 100 kilometers (62 miles), maintaining the apex altitude for several minutes to an hour or so depending on destination, then returning to an aerospaceport similar to the one it departed from. This scenario oversimplifies the problem, however. Assuming a market exists the technology necessary to develop a vehicle capable of such a transit is daunting. The vehicle must not only transition from a sea level-pressure environment of 80 percent nitrogen and 20 percent oxygen to a vacuum microgravity environment, but must also return safely. While propulsion poses obvious difficulties, efficiency is perhaps a more challenging area. Instead of three types of engines (turbofan to scramjet to rocket), perhaps a hybrid of the three can be developed. This would, however, represent a level of efficiency possibly requiring decades of practical application and research. A more near-term design may feature a two-staged system similar to Mojave Aerospace Venture's White Knight and SpaceShipOne. In addition, the airframe must be designed to maximize efficiency as the vehicle transitions from sea level to vacuum to the high-temperature environment of reentry, and then do it again and again as it fulfills "airline-like" operations. Lifting bodies and waveriders are just two examples of these airframe concepts.

An additional concern could be that of passenger comfort. Space motion sickness (SMS) is a condition that typically occurs during the first 72 hours of spaceflight and during transitions from different gravity environments. A 1990 study[12] by J.R. Davis and others indicated about 67 percent of Shuttle astronauts express symptoms of SMS. Scientists have not been able to determine the exact cause, but SMS appears to stem from several root causes. In general, it may be a result of imbalances in the inner ear caused by conflicting signals between fluid in the semicircular canals of the ear not having a gravity reference and visual disorientation. Mercury and Gemini astronauts did not report motion sickness, possibly because of close surroundings inside the small capsules and because a majority of the flight was spent buckled up. On the other hand, advances in biomedical research could mitigate the problem, either with drugs (e.g. phenergan, scopolamine) or with surgery (for business travelers who might take suborbital flights routinely). Scopolamine patches have proven themselves to be very effective in preventing terrestrial motion sickness and may also help with preventing space sickness. The results of a 1993 study indicate that Phenergan (Promethazine hydrochloride) appears to be even more effective in treating the symptoms of SMS.[13] It is likely that initial passengers will be required to be strapped in for the duration of their suborbital excursions. One of the results from the 2002 Futron Corporation space tourism market study indicates that if customers were required to be strapped in for the whole flight 36% of the potential clients would be somewhat less likely to take the flight versus the requirement not making a difference to 34% of the respondents.[14]

The same arguments made earlier for fast package delivery apply to high-speed aerospace transportation: people will demand more efficient services in the future as our world becomes more and more intricately linked by transportation and telecommunications routes. In the case of SRLVs, as in computer processing, low-cost, high-speed services will likely always be in demand. As SRLVs demonstrate reliably safe and efficient operations, more people, including investors, will become interested in their potential services.

In addition, as suborbital transportation becomes routine, the pursuit of orbital flights will likely become a new incentive and challenge.

Launch Company Profiles

Acceleration Engineering

Micky Badgero formed Acceleration Engineering to develop a rocket ship called Lucky Seven in pursuit of the Ansari X Prize. Lucky Seven employs methane/oxygen liquid rocket engines to generate 72,000 newtons (16,200 pounds-force) of thrust to lift the 2,515-kilogram (5,532-pound) vehicle to altitude. Engine cutoff is planned to occur at 52 kilometers (32 miles). Peak acceleration during ascent is 3 g. The vehicle will perform a ballistic reentry and deploy a parafoil to guide the vehicle to a vertical landing within one kilometer (0.6 miles) of the launch site.

The one-person company has released few details about the vehicle, which has been under development since the mid-1990s. Badgero, a computer science graduate student at Michigan State University, has stated that the vehicle is privately funded and that construction will continue in his garage as funds permit.

Advent Launch Services

Houston-based Advent Launch Services is developing the sea-launched Advent vehicle for the Ansari X Prize competition and beyond. The Advent is a winged booster rocket 11 meters (35 feet) high with a gross liftoff mass of about 5,700 kilograms (12,600 pounds). The rocket will burn liquid methane and oxygen to produce a thrust of 84,100 newtons (18,900 pounds-force). It takes off vertically from an ocean launch site, firing its engines for 97 seconds. The vehicle continues on a ballistic trajectory, reaching a peak altitude of 105 kilometers (65 miles); passengers experience three-and-a-half minutes of microgravity during this phase of the flight. Advent then performs an aerodynamic controlled glide, landing horizontally back at the launch location in the ocean.

Advent Launch Services president Jim Akkerman, a former NASA engineer with extensive propulsion systems experience, has assembled an 11-member core team and a volunteer network to make his concept a reality. Development of the Advent has thus far been confined to subscale models and engine testing. The company hoped to complete qualification of the propulsion system by the end of 2004.[15] The Advent is considered to be a forerunner of an orbital space tourism vehicle that the company hopes to construct.

American Astronautics

American Astronautics, headquartered in Lake Tahoe, Nevada, entered its Spirit of Liberty vehicle concept into the Ansari X Prize competition in January 2003. The vehicle, 17 meters (56 feet) tall and weighing 9,950 kilograms (21,875 pounds), is powered by a single kerosene/liquid oxygen liquid fuel booster that generates 155,700 newtons (35,000 pounds-force) of thrust. The main engine will fire for 81 seconds, generating accelerations of up to 4 gs. After engine burnout a seven-person crew cabin separates from the vehicle and continues a ballistic ascent, reaching a peak altitude of 110 kilometers (68 miles). The booster and capsule each descend using controlled aerobraking and parafoils; airbags cushion the landing of both vehicle sections.

American Astronautics is led by Bill Sprague, a 30-year veteran of a wide range of missile and launch vehicle programs. Construction of the Liberty is reportedly proceeding at a steady pace, although the company has released few details about the progress of its efforts.

Armadillo Aerospace

Armadillo Aerospace, based in Mesquite, Texas, is actively developing suborbital vehicle concepts for manned flight. Its current design, Black Armadillo, will use liquid propellant engines generating 133,500 newtons (30,000 pounds-force) of thrust that burn for 144 seconds. The vehicle, 7 meters (24 feet) tall and weighing 6,350 kilograms (14,000 pounds), will lift off vertically and achieve a maximum altitude of 108 kilometers (67 miles). Black Armadillo will then perform a ballistic descent and land vertically under rocket power; a previous design incorporated a parachute landing using a crushable nose cone.

Armadillo has made considerable progress to date, performing a number of tests of engines and other vehicle technologies and incorporating those results into the design of their suborbital vehicle. Armadillo originally planned to use hydrogen peroxide propellant, but switched to a "mixed monopropellant" of methanol and a 50% hydrogen peroxide solution after encountering difficulties obtaining high-quality hydrogen peroxide. The company is also considering developing a liquid oxygen/ methanol bipropellant engine. In 2002 the team demonstrated the potential of the engines by creating a rocket-powered hover chair. As recently as the first quarter of 2004, Armadillo completed short hops with its propulsion unit as it worked towards a demonstration of the vehicle's ability to hover, key to the powered descent design.

The Armadillo flight concept was finally successfully demonstrated June 15, 2004, when a subscale demonstrator flew to 40 meters (131 feet) altitude and landed. However, a second demonstration flight in August 2004 failed when the vehicle crashed after exhausting its propellant supply. Despite this setback, the Armadillo team remains committed to maturing its design, and has completed work on a second demonstrator vehicle. Flight testing of the design is expected to resume in 2005.

Armadillo Aerospace is led by John Carmack, a software developer who cofounded the computer games developer id Software. Carmack is funding the development effort using his personal funds. In late April 2004, Armadillo began the process of applying for an FAA launch license. Flight tests to date have been under the amateur exclusion to the launch licensing regulations.

Beyond-Earth Enterprises

Beyond-Earth Enterprises of Colorado Springs, Colorado is developing unmanned suborbital vehicles to serve the space memorabilia and related markets. The company's "Road to Space" program features the development of a progression of recoverable suborbital launch vehicles eventually capable of flying to 100 kilometers (62 miles). The latest flights of its test program took place on September 25, 2004, when the company launched a pair of one-third-scale demonstrators from Frederick, Oklahoma. One rocket, dubbed Sapphire, reached an altitude of over 4,572 meters (15,000 feet); its payload capsule landed by parachute and was successfully recovered.

Beyond-Earth Enterprises has a six-person staff led by CEO Joe Latrell. The company is initially marketing its rockets to glean revenue from the "gee-whiz" aspect of space flight, believing that there is a market for any item or object that has touched space. For fees as low as $80, the company is offering to launch small objects like business cards or photos on suborbital trajectories into space. Beyond-Earth hopes its suborbital rocket, with its 23-kilogram (50-pound) payload capacity, generates between $100,000 and $200,000 per flight. Each recoverable vehicle is expected to be capable of ten flights before retirement. This initial endeavor is expected to cost the company about $2 million. The company expects to have sufficient demand to allow at least one flight per month in order to keep its business and development plans on track.[16]

Fundamental Technology Systems

In Orlando, Florida, Fundamental Technology Systems is developing a rocket plane called Aurora. A ride on the Aurora will be similar to that of other high-performance craft operating closer to Earth. The Aurora has an 11-meter (36-foot) fuselage and a 9-meter (30-foot) wingspan, and is powered by a 44,480-newton (10,000-pounds-force) hydrogen peroxide and kerosene rocket engine. The vehicle features a pressurized cabin to allow the three-person crew (pilot, co-pilot, and mission specialist/passenger) to enjoy the flight without the aid of pressure suits. The flight profile is similar to that of a regular aircraft, with a horizontal takeoff, climb to altitude, descent, and runway landing.

Both co-founders, Ray Nielsen and Jim Toole, have over 25 years of experience designing high-performance aircraft. Recent work on the Aurora vehicle has focused on avionics and rocket engine development, although little progress on vehicle development has been reported to date. The company also assisted another suborbital vehicle developer, Scaled Composites, by providing the flight navigation unit for SpaceShipOne.

High Altitude Research Corporation

Huntsville, Alabama-based High Altitude Research Corporation (HARC) entered the Ansari X Prize competition in November 2003 with its Liberator vehicle. The Liberator, 13 meters (43 feet) tall and weighing 4,536 kilograms (10,000 pounds) at launch, is a single-stage design using two LOX/kerosene liquid-fuel engines that generate a total of 106,800 newtons (24,000 pounds-force) of thrust. The engines were originally designed by Space America, a defunct venture from the late 1990s to develop a low-cost orbital launch vehicle. HARC, which has developed a number of hybrid rocket motors, initially planned to use a small hybrid engine for an escape tower mounted on the top of the vehicle, but elected instead to develop a small liquid-propellant engine. Although the cabin is pressurized, the crew will wear pressure suits throughout the flight.

HARC has substantial experience conducting launches from sea-borne platforms, which it plans to use for the Liberator vehicle. The main engines will fire for one minute, after which the booster stage will separate and parachute back into the ocean, while the crew cabin continues on its ballistic trajectory to 100 kilometers (62 miles). During descent the cabin will deploy its own parachute and fall to an ocean landing point. Passengers can expect acceleration and deceleration of up to 5 gs.

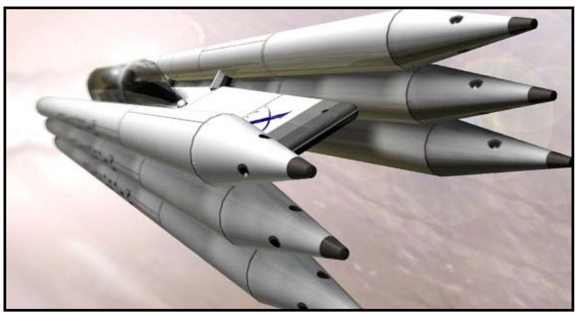
HARC, led by Gregory Allison, has extensive experience developing suborbital launch vehicles. It has produced hybrid rockets for atmospheric research since 1994, and held the world record for the highest amateur rocket flight until the GoFast private space launch in 2004. The corporation also claims one hundred successful firings of its hybrid rocket motors, as well as several launches from high altitude balloons. The company raised about $5 million as of the end of 2003, but expects it will require an additional $9.5 million in order to complete the full-scale Liberator.

Masten Space Systems

Masten Space Systems (MSS) of Santa Clara, California is a new entrant to the commercial suborbital spaceflight field, having opened for business in August 2004. The Masten concept is to develop a series of vertical takeoff vertical landing (VTVL) rockets called the Extreme Altitude (XA) line. These vehicles will cater to suborbital research markets such as high-altitude atmospheric measurements, low-cost solar astronomy, space particle and plasma research, low-cost exoatmospheric astronomy, near Earth object detection, microgravity research, and Earth observation. The XA-1.0 is planned to be able to lift a 100-kilogram (220-pound) payload to 100 kilometers (62 miles), and be able to repeat that flight several times in a single day. MSS plans to offer flights for between $20,000 and $30,000.

David Masten, a 12-year veteran of the information technology and management consulting fields, leads the company. The rest of the five-member core team is composed of members from various engineering fields; most team members are also members of grassroots space societies like the Experimental Rocket Propulsion Society and Artemis Society International. The company plans to follow an evolutionary approach and design a suborbital version to earn revenue and gain operations experience before scaling up the design into an orbital version.

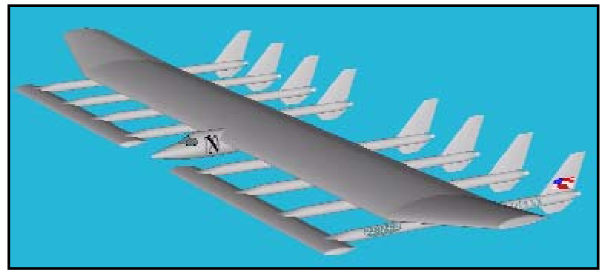
Micro-Space



Micro-Space, based in Denver, Colorado, is developing the Crusader X vehicle, whose design is spartan compared to most other designs. Crusader X consists of a "sled" pulled aloft by two parallel clusters of rockets. Six hydrogen peroxide and alcohol liquid-fuel engines will generate 1,334-2,224 newtons (300-500 pounds-force) of thrust each to propel the vehicle. The crew will rely on pressure suits to provide life support. Passengers will experience lift-off accelerations of 4 gs after a ten-second engine run-up. Powered flight will last 60 seconds, after which the vehicle will then enter a ballistic trajectory. Presumably, at apogee a passenger might be able to jump off for a solo parachute descent. The launch vehicle will descend to a water landing using a ballute and parafoil.

Micro-Space is a six-person team led by Richard Speck. The team is currently engaged in the testing and development of the Crusader X. Subscale versions of the liquid booster rockets have been flown. A crew cabin mock-up and a half-scale version of the vehicle's inter-rocket pod structure have also been fabricated. Parts of the full-scale boosters are said to be in the company's possession. Initial flight-testing was to have begun in late 2003, but there have been no public reports of the proceedings.

PanAero, Inc.



PanAero, Inc. is a Chantilly, Virginia-based firm that has developed numerous two-stage-to-orbit vehicle concepts, including the Condor-X rocket glider. It features a fuselage mounted in front of a large wing that supports eight rocket pods for propulsion. The flight profile calls for a horizontal takeoff followed by a slow climb to 35 kilometers (22 miles) at a speed of 370 kilometers per hour (226 miles per hour). This slow cruise through the densest layer of the atmosphere is needed to prevent air pressure from damaging the fabric-covered aluminum structure. Once at that altitude, the vehicle pitches up for a near-vertical climb through 70 kilometers (43 miles), after which the rocket engines are shut down.

After burnout, the Condor-X continues on a parabolic trajectory with a 100-kilometer (62-mile) apogee. Its large wing design serves as a speed brake and parachute during reentry to slow the vehicle down. The cabin is lowered by cables beneath the wing to enable the structure to act like a parachute for part of the descent profile, until the vehicle falls to an altitude of 6,000 meters (20,000 feet). Following this, the cabin retracts, and a glider landing brings the vehicle back to Earth at the original takeoff airstrip.

Len Cormier, a former naval aviator and engineer, leads the four-member team. If the Condor-X design is successful, the company will then focus on payload-carrying suborbital missions in order to fund further activities. Serving space tourists is viewed as a tertiary goal for the company's new vehicle. Little information is available about the Condor X development status beyond the concept definition stage.

Development of the Condor-X concept has continued past the awarding of the X Prize. PanAero seeks to convert the design into a scaled-down aircraft with an extremely low wing loading. The new vehicle is intended to: set altitude records for rocket-propelled aircraft; launch a one-ton rocket from 35 kilometers (22 miles) capable of placing 20-kilogram (44-pound) payloads into orbit for $100,000 a flight; and perform other high-altitude long-duration missions at a lower cost than existing aircraft.[17]

Rocketplane Ltd.

Rocketplane Ltd., formerly known as Pioneer Rocketplane, is proceeding with the development of its Rocketplane XP suborbital vehicle. The Rocketplane XP traces its heritage to an early 1990s Air Force spaceplane concept called Black Horse. Pioneer Rocketplane developed a derivative design that it called Pathfinder that has since evolved into the Rocketplane XP vehicle. The Rocketplane XP is powered by two conventional jet engines and a single 133,440-newton (30,000-pounds-force) liquid oxygen/kerosene rocket engine developed by ORBITEC. The 8,165-kilogram (18,000-pound) XP will take off under jet power from an airport and climb to about 6096 meter (20,000 feet), and then ignite its rocket engine for a two-minute burn. The vehicle flies a ballistic trajectory to an altitude of over 100 kilometers (62 miles). After reentry the Rocketplane XP reignites its jet engines for a runway landing.

Rocketplane Ltd. moved its offices from California to Oklahoma in 2004, opening offices in Oklahoma City. The company has raised over $30 million and qualified for investment tax credits from the State of Oklahoma in January 2004. George French is president of Rocketplane, while company co-founder Mitchell Burnside Clapp was named Director of Flight Systems at the company in August 2004. The company plans to begin commercial flights of the XP from the Oklahoma Spaceport in Burns Flat, Oklahoma, by January 2007. In October 2004 the company announced it had entered into a partnership with Incredible Adventures, of Sarasota, Florida, to market tourist flights on the XP once it enters service. The passenger price will be $99,500.

Scaled Composites

Scaled Composites of Mojave, California, has long been recognized as a creator of revolutionary aircraft. They are the developers of the Voyager aircraft that became the first to fly around the world nonstop without refueling. The company with sponsorship from computer magnate, Paul Allen recently completed privately funded human space efforts with its Tier One program.

Tier One consists of two vehicles: a carrier aircraft called White Knight and a rocketplane named SpaceShipOne. White Knight is a jet aircraft powered by two J-85-GE-5 engines that generate 34,250 newtons (7,700 pounds-force) of thrust. White Knight features a 25-meter (82-foot) wing with the fuselage mounted at the top of an anhedral. Equally-spaced twin booms serve as both landing gear and tail assemblies. SpaceShipOne is mounted externally below the fuselage.

SpaceShipOne is carried aloft by White Knight to an altitude of about 15,240 meters (50,000 feet), a journey that takes about one hour from takeoff. At that point SpaceShipOne detaches from White Knight and fires its single rocket engine. The Space Dev-developed engine is a hybrid rocket motor using hydroxyl-terminated polybutadiene (HTPB), and nitrous oxidizer. The engine burns for up to 90 seconds, propelling the vehicle to a maximum altitude of over 100 kilometers (62 miles) and speeds in excess of Mach 3.

SpaceShipOne's wing employs variable geometry to a safe or "carefree" descent. After apogee, the rear of the wing tilts up at a 60-degree angle into a "feather" position. This high-drag attitude permits the craft to descend in a stable configuration, requiring little effort by the pilot to maintain. Once below 24,384 meters (80,000 feet), the wing reverts to its original position for the unpowered drop back to the originating runway.

Since the public unveiling of the Tier One program in April 2003, Scaled Composites has put both vehicles through an extensive flight program at Mojave Airport, California. Captive carry flights, where SpaceShipOne remained attached to White Knight, started in May 2003, with glide tests of SpaceShipOne beginning in August. On December 17, 2003, SpaceShipOne performed its first powered flight, igniting its engine for 15 seconds, reaching Mach 1.2 and 20,665 meters (67,800 feet) altitude. Scaled conducted two more powered test flights on April 8 and May 13, 2004, flying up to Mach 2.5 and 64,435 meters (211,400 feet) on the May flight.

On June 21, 2004, SpaceShipOne performed its fourth powered test flight and its first attempt to break the 100-kilometer (62-mile) boundary of space. A roll oscillation shortly after engine ignition and a trim control malfunction late in the powered portion of the flight caused a trajectory excursion of approximately 30 kilometers (19 miles). That excursion kept the vehicle from achieving its planned maximum altitude of nearly 110 kilometers (68 miles), but it did make it to 100,124 meters (328,491 feet), just above the 100-kilometer (62-mile) mark. For that achievement the FAA awarded pilot Mike Melvill the first-ever pair of commercial astronaut wings.

On July 27, 2004 Scaled Composites formally announced its intent to perform the two flights required to win the Ansari X Prize, with the first scheduled for September 29, 2004. On that flight, also flown by Melvill, SpaceShipOne avoided the trajectory excursion experienced in June, but did go into a roll near the end of the powered portion of the flight. Despite the roll the vehicle reached an altitude of 102,870 meters (337,500 feet) and glided back to a safe landing. The flight was officially certified by the Ansari X Prize judging team as a successful first X Prize attempt flight dubbed X1.

On October 4 SpaceShipOne flew its second Ansari X Prize flight, X2, with Brian Binnie piloting the spacecraft. The vehicle avoided the rolls experienced during the previous flight and easily broke the 100-kilometer milestone, reaching a peak altitude of 112,000 meters (367,442 feet) before gliding back to a successful landing at Mojave Airport. The prize judging team certified this a successful flight the same day and declared SpaceShipOne the winner of the prize.

Scaled Composites entered the history books in April 2004 when it received the world's first license for a reusable, suborbital, piloted launch vehicle from the FAA. The license, LRLS 04-067, became effective on April 1, 2004. The license covers SpaceShipOne launch activities from Mojave Airport and remains in effect for one year.

The Tier One effort has been financially supported exclusively by Paul Allen, a billionaire who co-founded software company Microsoft. Allen and Scaled Composites CEO Burt Rutan formed a joint venture called Mojave Aerospace Ventures (MAV) that owns the intellectual property of the Tier One program. On September 27, 2004, MAV signed an agreement to license that technology to Virgin Group, a British conglomerate run by Sir Richard Branson. Virgin has created a new subsidiary, Virgin Galactic, which plans to contract with Scaled Composites to build suborbital vehicles based on SpaceShipOne, but with the ability to carry up to five passengers. The first of those vehicles, dubbed Virgin SpaceShip (VSS) Enterprise, is expected to enter service in 2007.

In November 2004 Mojave Aerospace Ventures was presented with a check for $10 million and a trophy for capturing the Ansari X Prize in a ceremony at the St. Louis Science Center in St. Louis, Missouri.

Space Transport Corporation

Space Transport Corporation (STC), located in Forks, Washington, entered the Ansari X Prize competition in December 2003. The company plans to develop the Rubicon Space Tourism Vehicle, which, unlike most other vehicles of competing teams, uses solid-propellant motors. Its initial design incorporates a cluster of seven, 30-centimeter (12-inch) diameter, 3-meter (10-foot) long solid rocket motors capped by a cylinder and nose cone assembly that will contain the crew compartment, avionics, and recovery system. Overall, the vehicle will be about 7 meters (23 feet) tall, 97 centimeters (38 inches) in diameter, and weigh 2,494 kilograms (5,500 pounds) at takeoff.[18]

Launch will occur from a location near the Pacific coast of the Olympic Peninsula in Washington State. The motors will ignite sequentially in opposed pairs, with the central engine igniting last. The Rubicon will then follow a computer-guided parabolic flight path to reach suborbit. A parachute recovery system will be used to slow the vehicle down enough to permit a safe ocean landing. Total flight time is expected to be about 25 minutes. The Rubicon will use GPS to advise the recovery vessels of its location. Following extraction, STC plans to refurbish the vehicle's motor casings for up to five launches before they are discarded.

The firm's two founders and sole employees, Eric Meier and Phillip Storm, began testing components for their Rubicon Space Tourism Vehicle in 2002. A number of volunteers work on the project, which has been supported by local businesses. Although STC plans to initially focus on the suborbital tourist market, the company is also looking to the small payload market as a potential revenue source for its long-term endeavors, and is designing an unmanned launch vehicle called the Nano-Satellite Orbital Launch Vehicle (N-SOLV).

The STC team is currently involved in testing and production of components for their vehicle. It states that development of the Rubicon's attitude control system and associated inertial sensing systems is complete and that the systems are ready for installation. In March 2004, STC conducted a successful test firing of its full-scale solid rocket motor. STC conducted an unsuccessful test flight of a scaled-down version of the Rubicon in August 2004. The vehicle exploded shortly after leaving the launch pad due to a rupture of one of its solid rocket motors.

SpaceDev

SpaceDev, a company that has established itself in the small satellite and propulsion fields, has recently signaled its intent to enter the commercial suborbital vehicle market as well. In September 2004 the company announced plans to develop Dream Chaser, a SRLV. The vehicle, superficially similar in shape to NASA's cancelled X-34 vehicle, is a winged vehicle that will take off vertically using a single hybrid rocket motor. The motor, using HTPB and nitrous oxide, will generate 444,800 newtons (100,000 pounds-force) of thrust. The vehicle, capable of carrying several passengers, will fly to 160 kilometers (100 miles) altitude before gliding back to a runway landing.

SpaceDev, based in Poway, California, and run by company founder Jim Benson, has already developed a number of smaller hybrid rocket motors based on intellectual property from the defunct American Rocket Company (AMROC). In September 2003 SpaceDev won a contract from Scaled Composites to provide the hybrid rocket motors for the Tier One program. SpaceDev plans to have the Dream Chaser enter service as soon as 2008 if the program is fully funded.

TGV Rockets

TGV Rockets, of Norman, Oklahoma, is actively developing a suborbital vehicle called MICHELLE-B. MICHELLE (an acronym for Modular Incremental Compact High Energy Low-cost Launch Experiment), will be 15 meters (48 feet) tall and weigh 38,556 kilograms (85,000 pounds). The vehicle will use six pressure-fed liquid oxygen and kerosene engines, each capable of generating 133,440 newtons (30,000 pounds-force) of thrust. MICHELLE-B's flight profile calls for a vertical launch to an altitude of over 100 kilometers (62 miles) followed by a vertical descent with the assistance of a drag augmentation system involving drag panels deployed from the sides of the vehicle. The engines are used later for landing after the vehicle has descended below 3,000 meters (10,000 feet). Passengers in the pressurized cabin should expect to experience over 3 minutes of microgravity and no more than 4.6 gs during the flight; they will experience only 30 seconds over 3 gs as the vehicle descends. Unlike some other vertical take-off, vertical landing SRLV designs, the MICHELLE-B will be actively piloted during its descent. TGV believes that manual control will improve the system's reliability and shorten the vehicle's development cycle.

TGV moved from Maryland to Oklahoma in 2003 and has a working relationship with the University of Oklahoma, involving sponsored research for several students and professors. TGV expects to spend about $50 million building the MICHELLE-B SRLV - approximately the same amount spent to build the DC-X a decade ago. MICHELLE-B served as TGV's entry in the Ansari X Prize competition, but the vehicle is primarily intended to serve science and technology customers. The company anticipates initiating a flight-testing program by late 2007 followed by its proposed revenue service if all goes as planned.[19]

Vanguard Spacecraft

Vanguard Spacecraft entered the Ansari X Prize competition in May 2003 with its vehicle, Eagle. The Eagle uses a three-stage combination of twelve liquid engines and four solid rocket motors, with a total thrust of 1.78 million newtons (400,000 pounds-force), to boost the vehicle to an altitude of 100 kilometers (62 miles). It has both drogue and main parachutes that deploy to slow the vehicle prior to splashdown. The vehicle will be able to transport three passengers or 270 kilograms (595 pounds) of payload while exerting a maximum of 3 g of acceleration force during the trip. The ballistic flight profile will also offer up to five minutes of microgravity.

Steve McGrath, of Bridgewater, Massachusetts, leads the six-person team, primarily drawn from the high-power amateur rocketry community. The team has performed a number of small-scale model launches to date, but has made limited public progress on the actual vehicle.

XCOR Aerospace

XCOR Aerospace of Mojave, California seeks to develop rocket-powered aerospace vehicles to bring space closer to the public. The company was founded in November 1999 with a small group of employees, many of whom previously worked for Rotary Rocket Company. Its primary focus has been engine development, and has built and tested engines with thrust ratings ranging from 67 to 8,000 newtons (15 to 1,800 pounds-force).

XCOR is taking an incremental approach to its reusable suborbital vehicle. To understand rocket-propelled aircraft operations, it initially created the EZ-Rocket. The EZ-Rocket is an adaptation of the Long-EZ homebuilt aircraft. The EZ-Rocket employs twin isopropyl alcohol/LOX liquid-fuel rocket engines to produce 3,560 newtons (800 pounds-force) of thrust. The engines give the craft a maximum speed of 360 kilometers per hour (220 miles per hour). The estimated ceiling is 3,000 meters (10,000 feet). To date, the aircraft has been flown fifteen times, demonstrating safe, reliable rocket-powered flight operations.

The long-term goal of the firm is the creation of its general-purpose suborbital vehicle called Xerus. This small canard and delta-winged craft is expected to carry space tourists and scientific payloads to the edge of space and back. Maximum speeds are foreseen to be around Mach 4. The vehicle will use a cluster of liquid oxygen/kerosene engines to take off from a runway and fly to 65 kilometers (40 miles) altitude, after which the engines shut down. Xerus then coasts to 100 kilometers (62 miles) altitude before gliding back for a runway landing.

XCOR foresees several markets for the Xerus. The vehicle can carry a pilot and single passenger on space tourism missions, or a pilot and scientific payloads that need to experience microgravity or extreme altitudes. Additionally, the Xerus will constitute the first stage of a future microsatellite delivery system. XCOR plans to offer launches of 10-kilogram (22-pound) satellites for $500,000.

An intermediate vehicle called the Sphinx is also currently in development. Specific performance details are currently not available. A crew of two will control the vehicle, which is intended to operate somewhere between the performance of EZ Rocket and Xerus to demonstrate XCOR's versatility in launch vehicle technology.

On April 21, 2004, XCOR received an FAA launch license, the second ever awarded. The license, LRLS 04-068, covers 35 missions of the Sphinx vehicle, a technology demonstrator for the Xerus, at Mojave Airport through the end of 2006. The license does not cover passenger or other revenue flights until after the initial test flights are completed.

Table 2: U.S. Commercial Suborbital Vehicles

Company	Vehicle Name	Vehicle Type	Takeoff	Recovery/Landing
Acceleration Engineering	Lucky Seven	Liquid Fuel Rocket	Vertical/Land	Parafoil/Land
Advent Launch Services	Advent	Liquid Fuel Winged Rocket	Vertical/Water	Glide/Water
American Astronautics	The Spirit of Liberty	Liquid Fuel Rocket	Vertical/Land	Parachute/Land
Armadillo Aerospace	Black Armadillo	Liquid Fuel Rocket	Vertical/Land	Powered Descent/Land
Beyond-Earth Enterprises	Sapphire	Solid Fuel Rocket	Vertical/Land	Parachute/Land
Blue Origin	Not Announced	Liquid Fuel Rocket	Vertical/Land	Powered Descent/Land
Fundamental Technology Systems	Aurora	Liquid Fuel Rocket Spaceplane	Horizontal / Land	Glide/Land
High Altitude Research Corporation	Liberator	Liquid Fuel Rocket	Vertical/Water Platform	Parachute/Water
Masten Space Systems	XA	Liquid Fuel Rocket	Vertical/Land	Powered Descent/Land
Micro-Space	Crusader X	Bipod Rocket Sled	Vertical/Land	Parafoil/Water
PanAero	Condo- X	Multi-pod Rocket Glider	Horizontal/Land	Glide/Land
Rocketplane Limited	Rocketplane XP	Liquid Fuel Rocket/ Jet Spaceplane	Horizontal/Land	Horizontal/Land
Scaled Composites	SpaceShipOne/ White Knight	Two Stage Aircraft, Rocket	Horizontal/Land	Glide/Land
Space Transport Corporation	Rubicon	Solid Fuel Rocket	Vertical	Parachute/Water
SpaceDev	Dream Chaser	Hybrid Engine Spaceplane	Vertical/Land	Glide/Land
TGV Rockets	MICHELLE-B	Liquid Fuel Rocket	Vertical/Land	Powered Descent/Land
Vanguard Spacecraft	Eagle	Three Stage Rocket	Vertical/Land	Parachute/Water
XCOR Aerospace	Xerus	Liquid Fuel Rocket Spaceplane	Horizontal/Land	Glide/Land

Space Tourism Company Profiles

Incredible Adventures

Incredible Adventures (IA) of Sarasota, Florida and Moscow, Russia has been catering to thrill seekers since 1993. The company started under the name MIGS etc, and introduced the concept of tourist flights aboard Russian MiG fighter jets. Over the years IA has expanded its business to include space-related adventures like zero-gravity flights using Russian IL-76 aircraft, cosmonaut training at Star City, Russia and high-altitude flights aboard MiG-25 fighter jets. In 1996, controlling interest in the company was sold to Norman Fast, a venture capitalist with experience in the adventure travel industry. In addition to Florida and Moscow, IA offers flying adventures in Australia and South Africa.

Incredible Adventures offers a diversified tour catalog. Customers can book adventure vacations featuring rides on high performance jet aircraft, historic war aircraft, racecars, high-speed power boats, military armored vehicles and submersibles. IA also offers a variety of fantasy military missions, bodyguard training, high-altitude skydiving, and shark diving experiences.

Incredible Adventures recently added suborbital flights to its offerings. IA has partnered with Rocketplane Ltd. to offer flights to 100 km aboard the Rocketplane XP. Flights are scheduled to begin launching from a spaceport in Oklahoma in early 2007. The adventure, referred to as Civilian Astronaut Spaceflight Training, is anticipated to be priced at $99,500.[20]

Space Adventures

Established in 1998, Space Adventures Ltd, headquartered in Arlington, Virginia, has the distinction of being the first provider of orbital trips to space. At a price reported to be about $20 million, Dennis Tito became the first commercial space passenger in April 2001with his 10-day orbital flight to the International Space Station (ISS), via the Russian Soyuz rocket. Tito was followed by Mark Shuttleworth the following April. A third orbital client, Gregory Olsen, commenced training in 2004 but has been temporarily removed from Soyuz flight status, pending resolution of a medical issue. Additional orbital candidates are in various stages of discussions or preparations for orbital flight.

Space Adventures expects to offer suborbital flights by the 2007 timeframe. As with orbital space tourist flights, the company is positioned to serve as the tour operator and/or broker between crewed suborbital launch vehicle vendors and space travelers. Space Adventures has arrangements with several of the Ansari X Prize competitors and other start-up developers for transporting passengers. The Xerus spacecraft from XCOR Aerospace and Suborbital Corporation’s C 21, a mini-shuttle design SOV vehicle under development by Russian Myashishchev Design Bureau; Burt Rutan’s Ansari X-Prize winner-SpaceShipOne ; and Rocketplanes hybrid rocket-powered aircraft design are some of the possible suborbital vehicles now featured in Space Adventures company publications. Currently, Space Adventures says that it will offer its flights for fares around $100,000, and has received deposits from over 100 potential customers.[21]

Virgin Galactic

Even before it won the Ansari X Prize, the efforts of Mojave Aerospace Ventures had begun to attract more investment in space tourism. On September 27, 2004, MAV signed a $26-million agreement to license their SRLV technology to Virgin Group, a British conglomerate run by Sir Richard Branson. Virgin has created a new subsidiary, Virgin Galactic, which plans to contract with Scaled Composites to build suborbital vehicles based on SpaceShipOne, but with the ability to carry at least five passengers.[22] The first of those vehicles, dubbed Virgin SpaceShip (VSS) Enterprise, is expected to enter service in 2007.

While the vehicle is under development, Virgin Galactic is proceeding with its marketing plans. The company expects to begin taking deposits on reservations in 2005. An initial price point espoused by the company is $215,000 for three days of flight training followed by a flight to suborbital space.

Spaceports

Launch and reentry sites – often referred to as "spaceports" – are the nation's gateways to and from space. Although their individual capabilities vary, these facilities provide launch pads and runways as well as the infrastructure, equipment, and fuel needed to process launch vehicles and their payloads prior to launch. The first such facilities in the United States emerged in the 1940s, when the federal government began to build and operate space launch ranges and bases to meet a variety of national needs. While U.S. military and civil government agencies were the original and are still the primary users and operators of these facilities, commercial payload customers have become frequent users of federal spaceports as well.

Federal facilities are not the only portals to and from space. The commercial dimension of U.S. space activity is evident not only in the numbers of commercially-procured launches but also in the presence of non-federal launch sites supplementing federally-operated sites. FAA/AST has licensed the operations of five non-federal launch sites. These spaceports serve both commercial and government payload owners.

This section describes the non-federal domestic spaceports capable of supporting reusable suborbital launch and landing activities. Descriptions and histories for Mojave, Oklahoma, New Mexico, Mid-Atlantic Regional and Texas spaceports are included.

Table 3: U.S. Spaceports

State/ Location	Federal	Non-Federal	Proposed
Alabama			√
Alaska		√	
California (Vandenberg AFB)	√	√	
Florida	√	√	
Mojave Airport, CA		√	
Nevada			√
New Mexico	√		√
Oklahoma			√
Texas			√
Utah			√
Virginia	√	√	
Washington			√
Wisconsin			√

FAA Licensed Spaceports

While the majority of licensed launch activity still occurs at U.S. federal ranges, much future launch and reentry activity may originate from private or state-operated spaceports. In order for a non-federal entity to operate a launch or reentry site in the United States, it is necessary to obtain a license from the federal government through FAA/AST. To date, FAA/AST has licensed the operations of five non-federal launch sites, two of which are described in this section. Three spaceports are co-located with federal launch sites, including the California Spaceport at Vandenberg AFB, California, the spaceport facilities operated by Florida Space Authority (FSA) at Cape Canaveral, and Mid-Atlantic Regional Spaceport (MARS) at Wallops Flight Facility, Virginia. The fourth licensed, non-federal spaceport is Kodiak Launch Complex in Alaska.23 East Kern Airport District of Mojave, California, was awarded the fifth non-federal launch site operators license in June of 2004. It is also the first inland launch siteto receive a license.

Mid-Atlantic Regional Spaceport

Mid-Atlantic Regional Spaceport

The Virginia Space Flight Center (VSFC) traces its beginnings to the Center for Commercial Space Infrastructure, created in 1992 at Virginia's Old Dominion University to establish commercial space research and operations facilities in the state. In 1995, the organization became the Virginia Commercial Space Flight Authority (VCSFA).

In late 2003, the states of Virginia and Maryland joined together to cooperatively operate the commercial spaceport at Wallops Island. Following this new partnership, the spaceport was renamed the Mid-Atlantic Regional Spaceport (MARS).

On December 19, 1997, FAA/AST issued VCSFA a launch site operator's license for the VSFC. This license was renewed in December 2002 for another five years. In 1997, VCSFA signed with NASA a Reimbursable Space Act Agreement to use the Wallops center's facilities in support of commercial launches. This 30-year agreement allows VCSFA access to NASA's payload integration, launch operations, and monitoring facilities on a non-interference, cost reimbursement basis. NASA and VSFC personnel work together to provide launch services.

MARS owns two launch pads at Wallops. Launch Pad 0-B is capable of supporting a variety of small- and medium-sized expendable launch vehicles (ELV) with gross liftoff weights of up to 225,000 kilograms (496,000 pounds) that can place up to 4,500 kilograms (9,900 pounds) into LEO. In September 2004, MARS completed construction of a 31-meter (103-foot) tall Movable Service Structure (MSS) on Launch Pad 0-B. The MSS provides access and protection from the environment for launch vehicles while they are on the launch pad. The site also includes a complete command, control, and communications interface with the launch range. An Air Force Orbital/Suborbital Program (OSP) Minotaur mission is currently scheduled for this site.[24]

In March 2000, VSFC acquired a second launch pad from EER Systems of Maryland. Launch Pad 0-A was built in 1994 for the Conestoga launch vehicle, which launched once in October 1995. VSFC started refurbishing Launch Pad 0-A and its 25-meter (82-foot) service tower in June 2000. Launch Pad 0-A will support launches of small ELVs with gross liftoff weights of up to 90,000 kilograms (198,000 pounds) and that are capable of placing up to 1,350 kilograms (3,000 pounds) into LEO. Launch Pad 0-A can support a number of small solid-propellant boosters, including the Athena 1, Minotaur, and Taurus. Launch Pad 0-B can support larger vehicles, including the Athena 2. MARS also has an interest in supporting future RLVs, possibly using its launch pads or three runways at Wallops Flight Facility.

NASA is in the process of constructing a $4-million logistics and processing facility at the Wallops facility, capable of handling payloads of up to 5,700 kilograms (12,600 pounds). MARS assisted in developing the facility requirements and will be working with tenants and programs in the facility.[25] Phase 1 of construction is nearing completion. The facility will include high bay and clean room environments. In conjunction with NASA Wallops, MARS is adding a new mobile Liquid Fueling Facility (LFF) capable of supporting a wide range of liquid-fueled and hybrid rockets. Construction of the LFF is currently in final integration phase.[26]

Mojave Airport Civilian Flight Test Center

Mojave Civilian Flight Test Center

The East Kern County, California, government established Mojave Airport in 1935 in Mojave, California. The airport is owned and operated by the East Kern Airport District, which is a special district with an elected Board of Directors and a General Manager. The airport serves as a Civilian Flight Test Center, the location of the National Test Pilot School (NTPS), and as a base for modifications of major military jets and civilian aircraft.

Major facilities at the Mojave Airport include the terminal and industrial area, hangars, offices, maintenance shop, and fuel services facilities. Rocket engine test stands are located in the northern portion of the airport. Aircraft parking capacity includes 600 tie downs and 60 T-hangars. The Mojave Airport also includes aircraft storage and a reconditioning facility and is home to several industrial operations, such as BAE Systems, Fiberset, Scaled Composites, AVTEL, XCOR Aerospace, Orbital Sciences Corporation, Interorbital Systems, and General Electric. The Civilian Flight Test Center consists of several test stands, an air control tower, a rocket test stand, engineering facilities, and a high bay building.

In the last two years, XCOR Aerospace has been performing flight tests at this facility and recently had multiple successful tests with the EZ-Rocket. On the 100th anniversary of the Wright Brothers' first powered flight, December 17, 2003, Scaled Composites flew its SpaceShipOne from Mojave, breaking the speed of sound in the first manned supersonic flight by an aircraft developed by a small company's private, non-governmental effort.

A major development milestone was reached June 17, 2004, when the FAA/AST awarded a launch site operator license to the East Kern Airport District. This license permits suborbital space flights to be conducted from Mojave Airport. The site license was not a requirement for launches of SpaceShipOne because the vehicle is air-launched; but is required for XCOR Aerospace RLV missions that are FAA-licensed.

The international news media descended on Mojave Airport for the first privately built manned spaceship to break the barrier of space in June 2004 by Scaled Composites and then again in late September and early October 2004 when Mojave Aerospace Ventures won the Ansari X Prize with two flights of SpaceShipOne.

Proposed Spaceports Seeking an FAA License

Oklahoma Spaceport

Burns Flat, Proposed Site of the Oklahoma Spaceport

The State of Oklahoma is interested in developing a broader space industrial base and a spaceport. In 1999 the Oklahoma State Legislature created the Oklahoma Space Industry Development Authority (OSIDA). OSIDA promotes the development of spaceport facilities, space exploration, space education, and space-related industries in Oklahoma. In 2000, the state legislature passed an economic incentive law offering tax credits, tax exemptions, and accelerated depreciation rates for commercial spaceport-related activities. In 2002, OSIDA awarded a contract to SRS Technologies to conduct an environmental impact study. The study, expected to continue through Summer 2005,[27] is a critical step toward receiving a launch site operator's license from FAA/AST. In the fall of 2003, OSIDA took another step toward receiving its license by awarding a contract to The Aerospace Corporation to conduct a safety study of the proposed site and operations.

Clinton-Sherman Industrial Airpark, located at Burns Flat, is the preferred site for a future spaceport in Oklahoma. Existing infrastructure includes a 4,100-meter (13,500-foot) runway, a large maintenance and repair hangar, utilities, a rail spur, and 12 square kilometers (5 square miles) of open land. The Oklahoma Spaceport will provide launch and support services for RLVs and may become operational in late 2006 or early 2007, becoming one of the first inland launch sites in the United States. The State of Oklahoma offers several incentives, valued at over $128 million over 10 years, to attract space companies to the state. Also, the state will provide a $15-million tax credit to the first corporation that meets specific qualifying criteria, including equity capitalization of $10 million and the creation of at least 100 Oklahoma jobs. Some organizations also may qualify for other state tax credits, tax refunds, tax exemptions, and training incentives. OSIDA has signed Memoranda of Understanding with several companies for use of the Burns Flat site.

Southwest Regional Spaceport

The State of New Mexico continues to make progress in the development of the Southwest Regional Spaceport (SRS). The proposed site of the spaceport is a 70-square-kilometer (27-square-mile) parcel of open land in the south central part of the state at approximately 1,430 meters (4,700 feet) above sea level. The spaceport concept is to support all classes of RLVs serving suborbital trajectories as well as equatorial, polar, and ISS orbits, and to provide support services for payload integration, launch, and landing. The facility will be able to accommodate both vertical and horizontal launches and landings, and will include two launch complexes, a runway, an aviation complex, a payload assembly complex, other support facilities, and a cryogenic fuel plant. The SRS is supported by the state through the New Mexico Office for Space Commercialization, part of the New Mexico Economic Development Department. New Mexico was selected to host the X Prize Cup in May 2004. The X Prize Cup Exhibition is scheduled for October 2005 at White Sands Missile Range (WSMR) and the X Prize Cup First Flight competitions are scheduled for October 2006 at WSMR.

Starchaser, a former X Prize contender based in the United Kingdom, has established a U.S. company and is also interested in launching from New Mexico. Starchaser Industries Incorporated, the American branch of Starchaser Industries, hopes to offer microsatellite launches and eventually space tourism from SRS beginning as early as 2006.

Texas Spaceports

Although several spaceports are currently being planned in the state of Texas, none have announced plans to accommodate SRLVs. However, Armadillo Aerospace does use a site in Rockwall County, Texas for short developmental “boosted hops” of their vehicle.[28] Armadillo plans to move testing to SRS once they earn a FAA launch license and are permitted to conduct engine firings longer than 15 seconds. Details on the development of the other Texan spaceports, such as the West Texas Spaceport, can be found in the FAA's 2005 U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies and Spaceports report, available from http://ast.faa.gov.

Appendix: A Brief History of Major U.S. Suborbital Vehicles

Historically, suborbital ELVs have been used to carry experiments designed to sample or otherwise measure the upper atmosphere and its behaviors, test new technologies related to spaceflight, and conduct astronomical observations. Suborbital ELVs also include intercontinental ballistic missiles (ICBMs), some intermediate range ballistic missiles (IRBMs), and anti-missile targets and interceptors.

The remainder of this section describes the evolution of nine different suborbital vehicles developed, tested, and launched between the early 1940s and the present.

The WAC-Corporal (1944-1950)

The Army pursued a rocket program during World War II that eventually led to a suborbital rocket called WAC. It is not clear what the term “WAC” means, though some have suggested that it was an acronym for “Without Attitude Control,” referring to the fact that the simple rocket had no stabilization or guidance system. In 1944, the Army Ordnance Department began funding a rocket development program for the California Institute of Technology (CIT). The ORDCIT (for “Ordnance” and CIT) project’s first product was the Private A, a small solid-propellant rocket designed to test basic principles of launch operations and flight stability. Over twenty Private A rockets were flown during December 1944. The ultimate goal of ORDCIT was the development of the Corporal, a liquid-fueled surface-to-surface missile. By late 1944, enough progress had been made to initiate the development of a small sounding rocket based on Corporal.

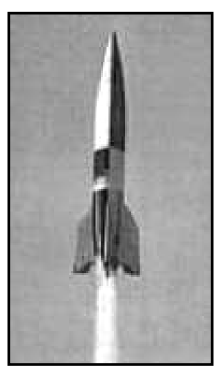
The planned sounding rocket was called WAC-Corporal, and was to carry 11 kilograms (25 pounds) of instrumentation to an altitude of at least 30 kilometers (100,000 feet). The WAC-Corporal was boosted into the air by a Tiny Tim solid-fueled booster (a heavy air-to-surface missile of the U.S. Navy), and powered by a liquid-fueled sustainer engine.

Following preliminary booster tests with subscale and dummy WACs, the first flight of a full WAC-Corporal occurred in October 1945. It reached an altitude of 70 kilometers (43 miles), but the nose-cone recovery mechanism failed.

After the initial WAC-Corporal rounds had been expended in 1946, a slightly improved WAC B model was built. This rocket had a lighter engine, a modified structure, and a new telemetry system. Between December 1946 and mid-1947, eight WAC B rockets were launched, after which the WAC-Corporal program was terminated. Although it was soon overshadowed as a high-altitude research rocket by the V-2, the WAC-Corporal formed the base for the development of a more capable and useful general-purpose sounding rocket, the RTV-N-8 Aerobee. Slightly modified WAC Corporal rockets were also used as the second stage of the RTV-G-4 Bumper test vehicle.

The WAC-Corporal was the first American rocket to escape the Earth’s atmosphere and would lead to the Aerobee sounding rocket, the Vanguard launch vehicle, the Titan missile, and (according to some experts) the Chinese Long March family.

The V-2 (1945-1952)



Operation Paperclip was initiated in 1945 by the United States military. American (and Soviet) forces recruited German engineers and scientists responsible for the development and launch of rocket-propelled vehicles for the Nazi army at the conclusion of World War II. The U.S. Government recognized that the V-2 represented a giant leap in technology, and set up Operation Paperclip to acquire rocket engineers, rocket components, and any other form of technology deemed critical to American national security.

Using about a hundred acquired V-2s, thousands of components, and a few hundred German engineers and scientists, the Americans succeeded in learning about advanced rocket technology. The V-2s launched by the United States Army from White Sands Missile Range in New Mexico during the 1940s were modified and improved with each flight. Early V-2 launches included telemetry packages, but it became clear that the V-2s could also carry scientific payloads. It was not known until much later that the Germans had already launched scientific experiments with even earlier versions of the rocket during World War II.

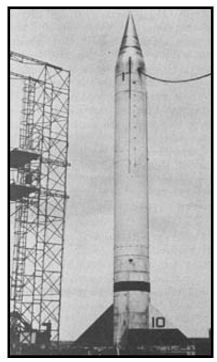
In 1946, the Naval Research Laboratory (NRL) was invited to participate in the Army's V-2 rocket program. As an established group ready to carry out upper atmospheric research, the NRL became the prime agency for conducting research with the V-2 program and for developing the technology to carry out the missions. Eighty experiments were performed between 1946 and 1951. As a result, new and valuable information was gained about the nature of the Earth's upper atmosphere and ionosphere.

The Bumper-WAC (1948-1952)

The Army also merged eight V-2s with the WAC-Corporal to support "Project Hermes," a research effort conducted between 1948 and 1952. This project aimed to study technical problems associated with rocket stage separation, high altitude flight dynamics and high altitude rocket stage ignition. The WAC-Corporal's liquid-fueled stage was simply mounted on the nose of the V-2 to create the Bumper-WAC. The WAC-Corporal second stage remained atop the nose of the V-2 for the first minute of flight. The V-2 then shut down, after providing a high altitude "bump" for the WAC-Corporal second stage. Following the first stage shutdown, the WAC-Corporal second stage ignited and fired for 45 seconds, completing the remainder of the flight.

The first six Bumper-WAC rockets were launched from White Sands. The first of these was launched on May 13, 1948. The vehicle flew to an altitude of 129 kilometers (80 miles) at a maximum speed of 4,410 kilometers per hour (2,740 miles per hour). Five more test flights were conducted at White Sands with mixed results. Bumper #5, launched on February 24, 1949, was the most successful launch test in the White Sands Bumper-WAC series and marked the first time a man-made object reached space. In 1950, Bumper-WAC tests moved to Cape Canaveral.

The Viking (1946-1957)



Meanwhile, recognizing that it had run out of V-2s to use for research projects, the NRL directed the development of a new sounding rocket called Viking, which was designed and built by the Glenn L. Martin Company in 1946. Viking employed a new innovation, a gimbaled motor for steering and intermittent gas jets for stabilizing the vehicle after the main power cutoff. The engine was one of the first three large, liquid-propelled, rocket-powered engines produced in the United States. A total of twelve Viking rockets were launched from 1949 to 1954. The first attained an 80-kilometer (50-mile) altitude and the eleventh Viking rose to 254 kilometers (158 miles), an altitude record for a single-stage rocket at the time. Through these Viking firings, the NRL was first to measure temperature, pressure, and winds in the upper atmosphere and electron density in the ionosphere, and to record the ultraviolet spectra of the sun. NRL also took the first high-altitude pictures of the Earth.

On October 5, 1954, during a launch over New Mexico, a camera mounted in an NRL Viking rocket took the first picture of a hurricane and a tropical storm, from altitudes as high as 160 kilometers (100 miles). The picture covered an area more than 1,600 kilometers (1,000 miles) in diameter, including Mexico and an area from Texas to Iowa. This was also the first natural color picture of Earth from rocket altitudes. The success NRL achieved in this series of experiments encouraged Laboratory scientists to believe that, with a more powerful engine and the addition of upper stages, the Viking rocket could be made a vehicle capable of launching an Earth satellite. This eventually led to the Navy's Vanguard project.

The Aerobee (1946-1965)

The NRL also used the Aerobee, supplementing the Viking capability for research. The Aerobee was developed from the Army's successful WAC-Corporal program. The rocket, which emerged in 1946 from a sounding rocket program managed by the U.S. Navy Bureau of Ordnance, was developed because the Navy wanted a vehicle that was less expensive and less cumbersome than the V-2. The first live firing of an Aerobee occurred in November 1947, and the Aerobee was in wide use by U.S. military research agencies from 1950 until the 1970s. These relatively inexpensive rockets were used for 31 upper atmosphere experiments specially suited to their capability. Later redesigned into the Aerobee-Hi with an enlarged fuel tank, it was used for three flights in 1957 in conjunction with the International Geophysical Year.

In the 1950s, the NRL used a balloon-rocket combination called Rockoon in experiments to investigate solar radiation and cosmic rays. The plastic balloon lifted the Deacon rocket to 21,300 meters (70,000 feet) where it was fired by a pressure-sensing device. Using this technique, the rocket could carry a 23-kilogram (50-pound) payload to an altitude of more than 130 kilometers (80 miles). Finally, the NRL devised systems using Nike boosters with several different second-stage rockets. These vehicles were used primarily to study the sun during the 1957-1958 International Geophysical Year. The NRL also launched Arcas sounding rockets (together with Air Force Cambridge Research Laboratory) from 1959 to the late 1960s, and the Arcon rocket from 1958 to 1959.

The Nike (1946 to present)

The Nike booster was introduced in 1946 during the development of the Nike-Ajax surface-to-air missile for the Department of Defense. Later it was used occasionally as a sounding rocket, but much more often as the boost stage of a multi-stage sounding rocket. The Nike-Deacon version (17 flights) used from 1953 to 1957 was much cheaper than the Aerobee, and unlike Rockoon could be launched from fixed launchers in two-and-a-half hours. It was used for "falling sphere" air density studies, atmospheric soundings, and for heat transfer studies launched from Wallops Island (then operated by the National Advisory Committee on Aeronautics, or NACA). From 1956 to 1961, Nike-Recruit and Nike-T40 versions were introduced to test ballistic capsule models for a total of eight flights. NACA used a Nike-Nike combination in the 1950s to study aerodynamic and thermodynamic effects on subscale aircraft models. Twenty years later the Air Force flew a series of Nike-Nike Smoke rockets, each with a payload consisting of a separable ten-degree nose cone filled with titanium tetrachloride solution. This left a smoke trail in the sky, allowing winds aloft to be determined by optical measurement. The Air Force was firing the rocket as late as 1979, when its 16th and final flight was conducted from Chilca in Peru.

Perhaps the most successful version of the Nike was the Nike-Cajun combination, introduced in 1956. The Nike-Cajun was the most often launched sounding rocket in the United States at 714 total flights, and second worldwide only to the Soviet MMR-06. The Cajun motor was developed for the NASA in the 1950s by Thiokol, providing a more modern but still affordable replacement for the World War II-era Deacon. This rocket was used to launch a wide variety of payloads, including general upper atmosphere experiments, magnetic field experiments, horizon photography to obtain weather data, ionosphere experiments, and astronomy payloads. While the Nike-Cajun was selected as the Nike-Deacon replacement by the Air Force and

NACA, the Navy selected the competing Asp motor in 1957 for its sounding rocket projects, having launched the variant 78 times until 1963. After NASA took over the Navy's sounding rockets, the new organization fired the remaining rockets and then converted to their favored Nike-Cajun configuration in 1963. NASA also used a Nike-Apache configuration from 1958 to late 1980 (697 flights), and the Nike-Tomahawk from 1963 to 1995 (395 flights). These rockets were launched from sites all over the world, including those mentioned above for earlier Nike variants, and from lesser-known sites like Alcantara in Brazil, Fort Churchill in Canada, and Arecibo in Puerto Rico. There were nine variants of the Nike.

The Nike-Tomahawk, Nike-Orion and Taurus-Nike-Tomahawk versions are still used today, launched primarily from NASA's Wallops Flight Center. A Nike-Black Brant version is also in use today, and is a combination Nike booster with a Canadian Black Brant first stage.

Loki (1951-1985)

The Loki was an American unguided solid-propellant anti-aircraft rocket adapted to use as a meteorological sounding rocket. In 1956, the Cooper Development Corporation (CDC) received a contract for large-scale production of sounding rockets of the Loki-Dart type for use as weather research vehicles. This resulted in the Rocksonde family of sounding rockets, of which several thousand were built in the following years. The Rocksonde could reach an altitude of about 60 kilometers (37 miles), and the falling chaff was tracked by a ground-based wind-sensing system to obtain wind speed and direction data from high to medium altitudes. It continued to be used throughout the 1960s, but was eventually replaced as the Air Force's Loki-Dart.

In the early 1960s, the low-cost Loki-Dart sounding rockets could only carry a passive chaff payload to high altitude. For more sophisticated payloads like temperature transmitters, the Air Force had to use the significantly more expensive Arcas rocket. The Loki Dart was eventually replaced in the early 1970s by the larger Super Loki family of sounding rockets. The last U.S. Government launch of a Loki series rocket was on December 30, 1985 from Wallops Island. However, surplus Lokis continue to support amateur and educational flights in the U.S. and Australia.

Honest John/Taurus (1951 to present)

The Honest John was the U.S. Army's first nuclear-tipped surface-to-surface rocket. This missile's booster was mated to a Nike booster from 1955 to 1967 for a total of 39 flights designed to test gliding characteristics, heat transfer issues, and the parachute system destined for use on the Viking Mars lander missions. Other heat transfer tests were conducted between 1956 and 1960 using an Honest John-Nike-Recruit (16 flights), Honest John-Nike-T40 (one flight), Honest John-Nike-Deacon (one flight), and Honest John-Nike-Nike (21 flights) combinations. Later, the Honest John was incorporated into a rocket called the Exos, developed by the University of Michigan with the assistance of NACA under a contract from the Air Force Cambridge Research Center (AFCRC). It was a three-stage rocket combining an Honest John first stage, a Nike Ajax second stage, and a Thiokol Recruit third stage. The first flight test of an all-up Exos rocket occurred in June 1958, and the rocket was flown until 1965 only 10 times.

The direct descendant of the Honest John missile still in use today is the Taurus (introduced in 1977 and not to be confused with the Taurus orbital launch vehicle from Orbital Sciences Corporation), now mainly used as a booster for suborbital rockets launched from Wallops.

Terrier (1959-present)

The Terrier missile, developed as the U.S. Navy's first operational shipborne medium-range surface-to-air missile, became the stock from which a long lineage of sounding rockets emerged.

Several missiles were converted in 1959 as the Terrier-Asp and Terrier ASROC Cajun sounding rockets, and later the very successful Terrier-Tomahawk, launched from Barking Sands, Hawaii and Eglin, Florida between 1964 to 1980. The Terrier-Sandhawk was introduced in 1967 and was used until 1977, having been launched from Johnston Atoll in the Pacific, Poker Flat in Alaska, and Barking Sands to altitudes of between 350 to 450 kilometers (217 to 280 miles). The larger Terrier-Malemute was developed in 1977 and was launched until 1990 from Barking Sands, Wallops Island, Andoya (in Norway), Poker Flat, Kwajalein Atoll, Punta Lobos (in Peru), and Sonde Stromfjord (in Greenland).

The Terrier-Orion is the most recent version of the Terrier rocket series, first launched in 1994 from Wallops Island. This version uses an Orion rocket, developed in the 1960s, as the second stage. The rocket is still in service today, launching from Wallops Island and Woomera in Australia. Slightly different versions of this rocket, the Terrier-Malemute and Terrier-Oriole, are also launched from time to time.

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