Suborbital Reusable Launch Vehicles *and* Applicable Markets

October 2002

Prepared by
THE AEROSPACE CORPORATION
J.C. MARTIN and G.W. LAW
Space Launch Support Division
Space Launch Operations
Space Systems Group

Prepared for
U.S. DEPARTMENT *of* COMMERCE
OFFICE *of* SPACE COMMERCIALIZATION

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THE AEROSPACE CORPORATION
El Segundo, CA 90245-4691

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U. S. DEPARTMENT OF COMMERCE
OFFICE OF SPACE COMMERCIALIZATION
Herbert C. Hoover Building
14th and Constitution Ave., NW
Washington, DC 20230
(202) 482-6125, 482-5913

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Preface

This report has been prepared by The Aerospace Corporation for the Department of Commerce, Office of Space Commercialization, under contract #SB1359-01-Z-0020. The objective of this report is to characterize suborbital reusable launch vehicle (RLV) concepts currently in development, and define the military, civil, and commercial missions and markets that could capitalize on their capabilities. The structure of the report includes a brief background on orbital vs. suborbital trajectories, as well as an overview of expendable and reusable launch vehicles. Current and emerging market opportunities for suborbital RLVs are identified and discussed. Finally, the report presents the technical aspects and program characteristics of selected U.S. and international suborbital RLVs in development. The appendix at the end of this report provides further detail on each of the suborbital vehicles, as well as the management biographies for each of the companies.

The integration of suborbital RLVs with existing airports and/or spaceports, though an important factor that needs to be evaluated, was not the focus of this effort. However, it should be noted that the RLV concepts discussed in this report are being designed to minimize unique facility requirements. The characterization of planned U.S. spaceports, combined with the contents of this report, would help promote cooperative development between spaceports and RLVs.

The Aerospace Corporation is a private, non-profit, California Corporation that manages a federally funded research and development center. Aerospace provides systems engineering and development support for U.S. civil, military, and commercial space systems. Though Aerospace's primary customer is the Department of Defense, Aerospace does commit a significant portion of its resources to civil and commercial clients.

Acknowledgements

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Executive Summary

The purpose of this report is to survey and characterize suborbital reusable launch vehicles (RLVs) [1] in development, as well as to identify current and emerging suborbital market opportunities that these systems may enable.

Over the past 30 years, NASA has accepted the burden of developing technologies that will enable cheaper access to *orbital* space, as evidenced by its past X-programs and the current Space Launch Initiative. Various private companies have also attempted, and are still attempting, to develop new RLV systems for orbital space applications. However, the large development costs of such systems, coupled with the downturn of the low Earth orbit market (e.g., Iridium, GlobalStar), have made private sector development of orbital RLV systems increasingly difficult at this time. Given these hurdles, many commercial space transportation companies have begun shifting focus toward suborbital market opportunities, for which the technical challenge is much lower and the cost of market entry less expensive.

There are a number of current and emerging suborbital market opportunities upon which suborbital RLVs can capitalize. Current suborbital markets are served mostly by expendable sounding rockets, and include national missile defense tests, as well as high-altitude, astronomical, and micro-gravity research missions. Each of these areas presents a viable opportunity for suborbital RLVs. Further, there are a number of new markets that could emerge with the advent of an operational suborbital RLV. These emerging suborbital markets include military surveillance, commercial/civil earth imagery, fast package delivery, high speed passenger transportation, media, advertising, sponsorship, space tourism, and even "space diving."

For suborbital RLV concepts being designed for dual-use capability (i.e., the same vehicle type used by both U.S. Government and commercial customers), the development of multiple markets (i.e., military, intelligence, civil, commercial) might significantly lower customer costs. With the expansion of such markets, and a consequent increase in flight rate for dual-use-design RLVs, fixed operating costs could be amortized over more flights. This would translate into lower costs to the government customer (since commercial products and services supplied to the government are regulated by profit caps), and potentially the commercial customer as well. Additionally, if the growth of government and commercial markets contributes to a significant increase in vehicle production, manufacturing economies of scale would contribute to lowering the cost per vehicle—an advantage to both government and commercial customers. Significant cost reduction would allow greater national security and civil benefits to be achieved with limited budgetary resources.

Suborbital RLV development is being pursued by a number of entrepreneurial organizations. Whereas orbital space transportation development has traditionally taken a "one big step" approach, these organizations have elected to take an incremental approach, beginning with a suborbital system and gradually transitioning to an orbital capability. This step-by-step approach is similar to the way aircraft have developed since the Wright brothers flight of 1903. Since suborbital RLVs are much less complex than orbital systems, the goal of these entrepreneurial organizations is more attainable.

[1] The use of the term "reusable launch vehicle (RLV)" is at present a subject of discussion. Use of this label in the report does not represent any attempt to take a position regarding whether or not another term should be adopted. Because no other label has yet gained wide endorsement, it appeared appropriate to continue using the traditional term in order to avoid possible misunderstandings that might be engendered by use of an alternative.

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PART 1

INTRODUCTION

1 Introduction

1.1 Overview

Space has long provided opportunities for the civil, military, and commercial sectors. NASA has launched satellites to orbit for such applications as atmospheric research and terrestrial monitoring, and has launched payloads on suborbital trajectories for astronomical and micro-gravity research. The military has placed satellites in orbit for such missions as communications, surveillance, and navigation. Over the last two decades, commercial industry has had an increasing presence in space. The benefits of space for mobile satellite communications, TV broadcasting, high-speed data transfer, and commercial navigation, just to name a few, are being realized today by commercial businesses. Furthermore, the potential opportunities offered by space for manufacturing, mining, and space-based solar power are becoming more and more appreciated by the private sector. The term “space commercialization” refers to the use of space for such profit-motivated, commercial purposes.

Most of these space missions focus on the *orbital* environment, but the cost of getting to orbit is very high. NASA has accepted the burden of developing technologies that will enable cheaper access to orbital space, as evidenced by its past X-programs, and the current Space Launch Initiative. Various private companies have also attempted, and are still attempting, to develop new reusable launch vehicle (RLV) systems. However, the large development costs of such systems, coupled with the downturn of the Low Earth Orbit market (e.g., Iridium, GlobalStar), have made private sector development of orbital RLV systems increasingly difficult at this time.

Given these hurdles, entrepreneurs within the commercial space transportation industry have begun shifting their focus towards suborbital market opportunities, for which the technical challenge is much lower and the cost of market entry less expensive. The $10 million X-Prize for the first passenger-carrying (or passenger-ballast-equivalent-carrying) suborbital vehicle is, like aviation prizes of the past, serving as a potent catalyst for these entrepreneurial efforts. Beyond this, state-sponsored spaceport development initiatives are seeking both to encourage vehicle development and provide staging facilities specially designed to accommodate suborbitally-oriented activities.

The purpose of this report is to survey and characterize the suborbital RLVs in development, and identify the current and emerging suborbital market opportunities that these systems can capitalize upon.

1.2 Background

1.2.1 The Suborbital Space Environment

In theory, an object can be in orbit around the Earth at any altitude, as long as it is imparted with enough velocity. The term “suborbital” refers to an object that is not imparted with enough energy (and hence enough velocity) to reach orbit. For various reasons beyond the scope of this discussion, 115 miles (approximately) is the minimal altitude at which objects are placed in orbit. At this altitude, the velocity required to achieve orbit is roughly 30,100 feet per second, or 20,500 mph. Suborbital launch vehicles are not designed to achieve these speeds, and are generally much smaller than orbital vehicles since they carry less propellant.

The altitude at which "space" begins is still the topic of much debate, but many consider space to begin at an altitude of 50-miles, since the U.S. Air Force grants astronaut "wings" for any altitude achieved beyond 50 miles. Just beyond the edge of space, at 62 miles (100 km), is where the X-prize competition has set its goal for sending civilian passengers to space. As a comparison, civilian aircraft operate at altitudes below 18 miles. Even high performance military aircraft and high-altitude weather balloons do not travel past the upper stratosphere (approximately 34 miles). Figure 1 displays the operational altitudes of various aircraft and spacecraft, and illustrates that there is a significant portion of the space environment served only by sounding rockets.

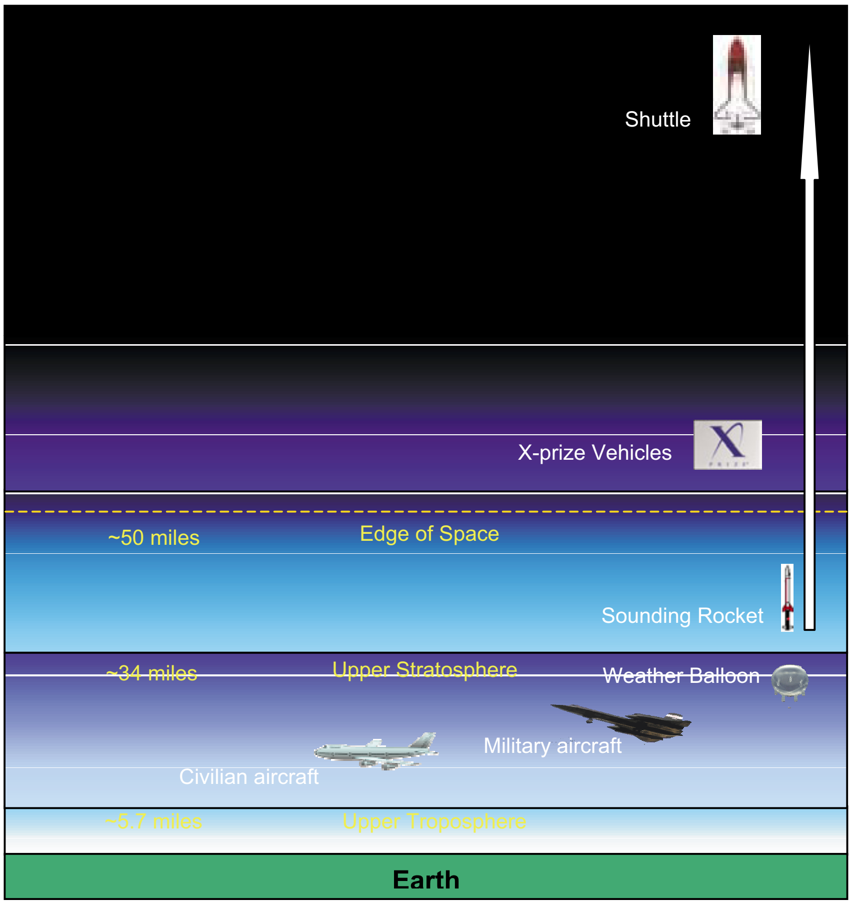


Figure 1. Operational Altitudes of Various Aircraft and Spacecraft

1.2.2 Suborbital vs. Orbital Expendable Launch Vehicles

A launch vehicle is the device used to transfer humans or cargo along suborbital and orbital trajectories. With the exception of the Space Shuttle, all launch vehicles in use today are disposed of after each launch, and are referred to as expendable launch vehicles (ELVs).

ELVs represent an evolution of long-range ballistic missiles first developed by the Germans in WWII. This missile was known as the V-2 rocket (also the A-4 rocket), and was pioneered by German scientist Wernher Von Braun. Following the War, Von Braun and his team of German scientists came to the United States and worked for the Army Ballistic Missile Agency at Redstone Arsenal in Huntsville, Alabama. The team led the U.S. development of the Jupiter and Redstone intermediate range ballistic missiles, which had their heritage with the V-2 rocket. The Jupiter C was used to launch America's first satellite, Explorer I, into space on January 31, 1958. When the Space Race began in 1960, the U.S. Government determined that the fastest way to get to space, and the moon, was by leveraging experience with the Army Ballistic Missile Agency's missiles. In 1961, a modified Redstone rocket was used to send Alan Shepard on a sub-orbital flight. Eight years later in 1969, the Saturn V, an evolution of the rockets developed at Redstone Arsenal, was used to carry Neil Armstrong, Buzz Aldrin, and Michael Collins to the moon. Today's U.S. medium and heavy-lift ELVs (e.g., Delta, Atlas) can also trace their origins to the rockets developed at Redstone arsenal, and ultimately to the V-2 rocket.

The ELVs in use today that achieve suborbital velocities are known as sounding rockets. Sounding rockets derive their name from the nautical term "to sound," which means "to take measurements." This is because sounding rockets do not place payloads in orbit, but rather provide the only means of making in-situ measurements at altitudes between the maximum altitudes for balloons (about 30 miles) and the minimum altitude for satellites (100 miles, although sounding rockets are also launched to altitudes as high as 870 miles). Figure 2 displays the configuration of a typical sounding rocket [ref 1].

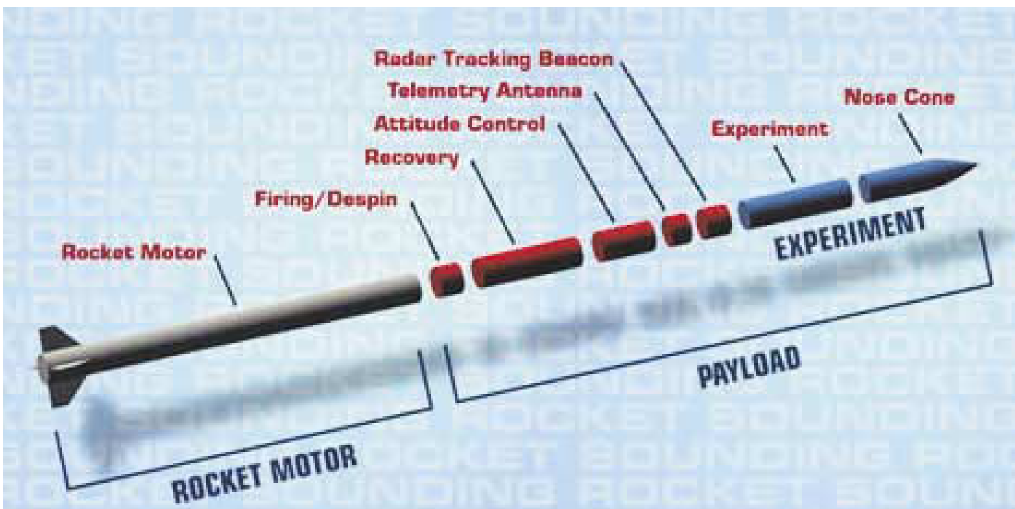


Figure 2. Sounding Rocket Configuration (*Image provided courtesty of NASA.)*

The profile for a sounding rocket mission, as displayed in Figure 3, is much different than an orbital launch vehicle mission. The sounding rocket payload follows a parabolic trajectory and is retrieved less than 30 minutes after launch, whereas the orbital payload maintains motion around the Earth for an extended period of time (usually years). Though the flight time on a sounding rocket is short, a significant amount of data is collected. Figure 4 displays the difference between these two trajectories.

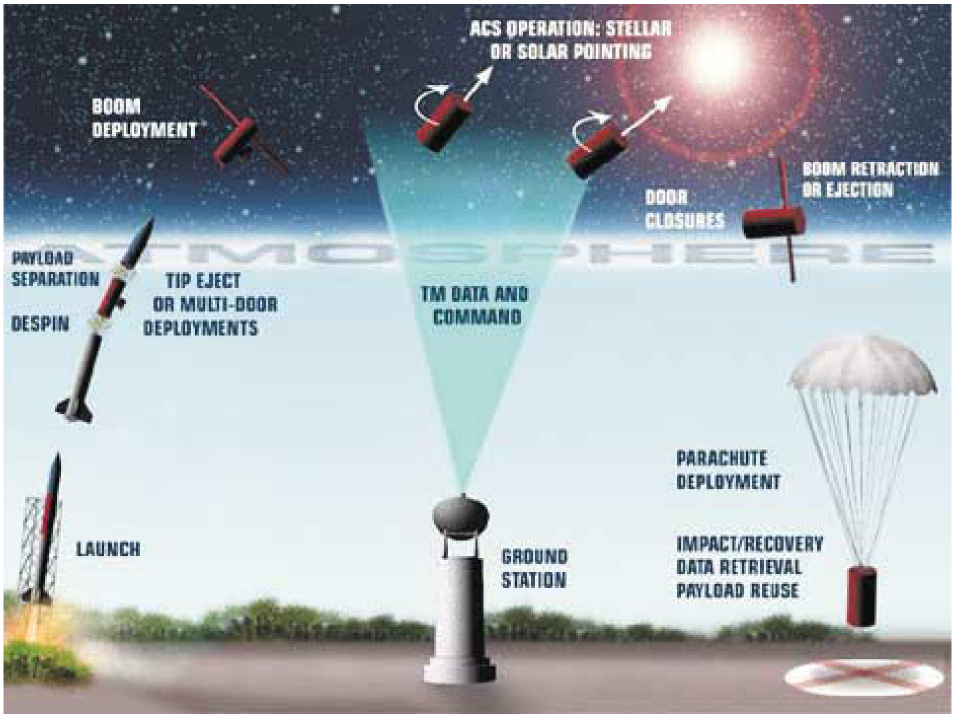


Figure 3. Sounding Rocket Mission Profile (*Image provided courtesy of NASA.)*

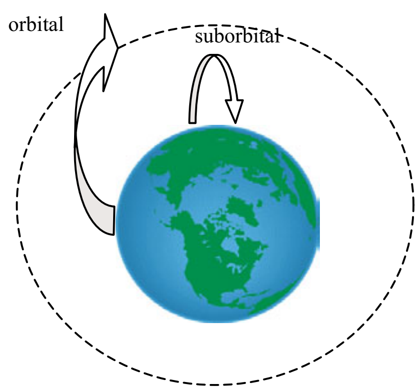


Figure 4. Suborbital and Orbital Mission Profiles

Sounding rocket missions are much less expensive than orbital launch vehicle missions, partly because the launch system itself is much simpler and requires much less ideal velocity, but also because the payload can often be retrieved, allowing the payload or parts of the payload to be refurbished and flown again [ref 1].

Orbital ELVs, on the other hand, are much larger, more complex, and consequently more expensive than sounding rockets. Because of the high velocities needed to obtain orbit, the mass and volume of orbital expendable launch vehicles consists mostly of propellant. Further, orbital ELVs transport much heavier payloads than sounding rockets (10-100 times), thus requiring the launch vehicle to have even more energy. (In fact, orbital systems incorporate liquid propulsion, as opposed to the solid propulsion systems of sounding rockets, therefore requiring additional hardware; e.g., fuel and oxidizer lines, tanks.) This translates to more complex systems, more support structures, and ultimately much larger vehicles. Figure 5 displays Boeing's Delta III launch vehicle and how it compares in size to the suborbital Nike-Orion sounding rocket. As Figure 5 illustrates, the difference in size is dramatic. The associated increase in size and complexity further translates to higher costs. As a comparison, the launch cost for Bristol Aerospace's Black Brant V is approximately $200,000, and for the larger Black Brant XII approximately $600,000; while the launch costs for orbital expendable launch vehicles is between $12 M (for a Pegasus) and $450 M (for a Titan IV) [ref 2].

Figures 6 displays a table of the current fleet of sounding rockets used by NASA, and Figure 7 displays a table of U.S. orbital ELVs currently in service.

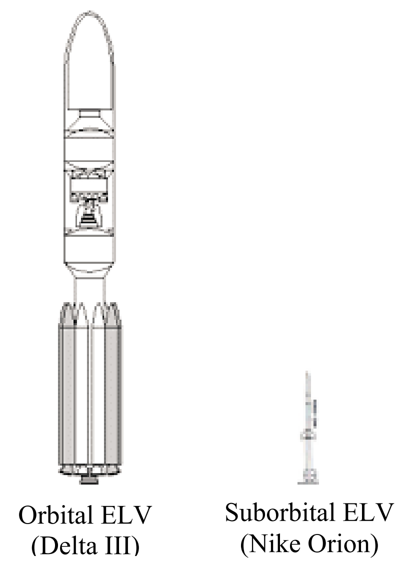
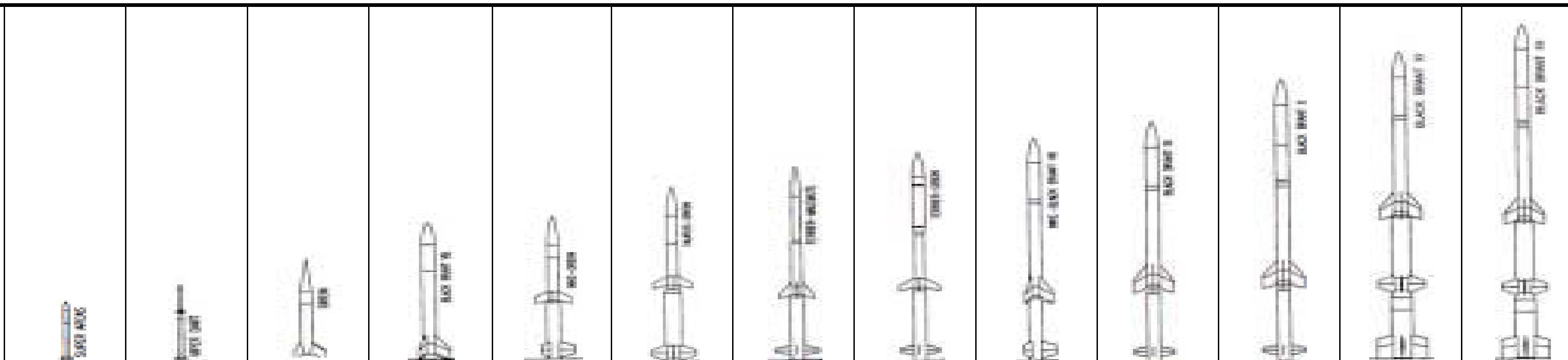


Figure 5. Size Comparison of Orbital and Suborbital ELV

Nike-Orion image provided courtesy of NASA

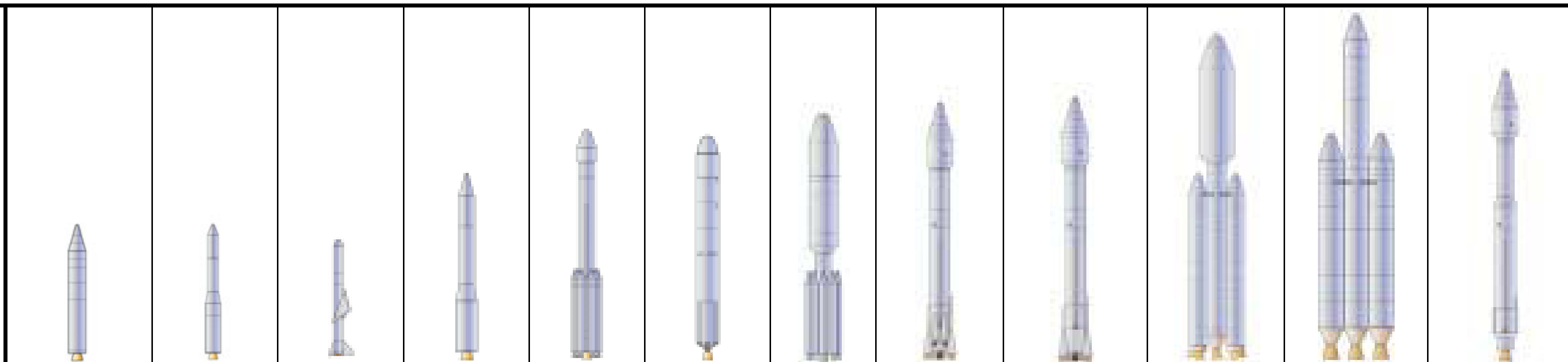


Vehicle	Super Arcas	Viper Dart	Orion	Black Brant V	Nike-Orion	Taurus-Orion	Terrier-Malemute	Terrier-Orion	Nike-Black Brant	Black Brant IX	Black Brant X	Black Brant XI	Black Brant XII
Prime Contractor	Atlantic Research Corp.	Integrated Team**	Integrated Team**	Bristol Aerospace	Integrated Team**	Integrated Team**	Integrated Team**	Integrated Team**	Bristol Aerospace	Bristol Aerospace	Bristol Aerospace	Bristol Aerospace	Bristol Aerospace
NASA Maiden Flight	1965	1972	1974	1972	1977	1978	1975	1994	1976	1982	1981	1990	1990
Stages		2	1	1	2	2	2	2	2	2	3	3	4
Payload Capability	8-18 lbs	16-22 lbs	75-250 lbs	300-1500 lbs	200-600 lbs	100-600 lbs	200-500 lbs	200-800 lbs	600-1200 lbs	300-800 lbs	150-800 lbs	500-1300 lbs	250-1000 lbs
Altitude	37-52 miles	54-68 miles	37-56 miles	37-217 miles	46-108 miles	77-186 miles	248-435 miles	46-140 miles	100-233 miles	217-341 miles	155-808 miles	155-435 miles	310-870 miles
Types of Missions	Plasma Physics	Meteor-ological	Student Mission	Plasma Physics	Student Mission	Chemical Release	Plasma Physics	Plasma Physics	Astronomy & Astrophysi cs	Astron-omy, Astro-physics, & Micro-gravity Research	Plasma Physics	Plasma Physics	Plasma Physics
Launch sites	Various Sites*	Various Sites*	Various Sites*	Various Sites*	Various Sites*	Various Sites*	Various Sites*	Various Sites*	Various Sites*	Typically WSMR	Various Sites*	Various Sites*	Various Sites*

*Worldwide launch locations available. U.S. launch locations include: Poker Flat Research Range (Alaska), WFF (VA), WSMR (NM), Kwajalein (Marshall Islands)

**Integrated Team consists of Litton PRC (program management, now Northrop Grumman), Orbital Sciences, Boeing, Arcata Associates, and Reliable System Services

Source: NASA Sounding Rocket website @ www.nsroc.com, Space Systems Forecast (January 2002) and World Space Systems Briefing (September 2001)



	Athena	Minotaur	Pegasus	Taurus	Delta 2	Titan 2	Delta 3	Atlas 2	Atlas 3	Titan 4B	Delta 4	Atlas 5
Vehicle	Athena	Minotaur	Pegasus	Taurus	Delta 2	Titan 2	Delta 3	Atlas 2	Atlas 3	Titan 4B	Delta 4	Atlas 5
Company	Lockheed Martin	Orbital Sciences	Orbital Sciences	Orbital Sciences	Boeing	Lockheed Martin	Boeing	Lockheed Martin	Lockheed Martin	Lockheed Martin	Boeing	Lockheed Martin
First Launch	1995/1998	2000	1990	1994	1990	1988**	1998	1991	2000	1997	TBD	2002
Stages	2 (Athena 1) 3 (Athena 2)	4	3	4	3	3-4	2	2	2	2	2 3 (Heavy)	2 3 (Heavy)
Payload Performance (LEO)	1,805 - 4,520 lbs	1,000 lbs	1,000 lbs	2,600-3,020 lbs	11,330 lbs	4,200 - 7,800 lbs	18,280 lbs	16,100-19,000 lbs	19,050-26,630 lbs	47,800 lbs	18,600-50,800 lbs	22,707-45,328 lbs
Payload Performance (GTO)	1,290 lbs	--	--	900 lbs	4,120 lbs	--	8,400 lbs	6,200-8,200 lbs	9,920 lbs	12,700 lbs (GEO)	9,285-28,950 lbs	8,752-27,880 lbs
Launch Sites	CCAFS, VAFB, Kodiak	CCAFS, WFF, VAFB, Kodiak	CCAFS, WFF, VAFB	VAFB	CCAFS	VAFB	CCAFS	CCAFS, VAFB	CCAFS	CCAFS, VAFB	CCAFS, VAFB	CCAFS

**First launch of refurbished Titan 2 ICBM. Titan 2 also used for Gemini program launches, 1964-1966.

Sources: *FAA/AST report "2002 U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports", AIAA International Reference Guide to Space Launch Systems, 3rd Edition, www.boeing.com, www.ilslaunch.com, www.orbital.com*

Figure 7. Orbital Expendable Launch Vehicles

1.2.3 Suborbital vs. Orbital Reusable Launch Vehicles

The term "RLV" refers to a launch system that can be re-used for multiple launches, instead of being disposed of after each launch like an ELV. Operationally, orbital RLVs could offer a number of advantages over ELVs. These could include greater reliability and safety, quick turnaround time, more versatile performance, high flight rate capability, and lower operating cost. Since ELV hardware is disposed of after each launch, ELVs have a very high operating cost (i.e., a new system is manufactured for each launch). By contrast, RLVs, for sufficiently high flight rates, should be less expensive to operate. Given the potentially significant operational advantages of RLVs, a number of effective applications become evident. For example, NASA could carry out its research missions at lower cost. The military could be provided with rapid space access for surveillance, high-altitude reconnaissance, or ordnance delivery. And, new commercial markets such as space tourism, fast package delivery, or micro-gravity processing could be developed.

However, for a number of reasons, orbital RLVs have proven challenging to develop. For example, the evolution of ELVs has benefited from direct transfer of technical experience from military missile system programs, whereas orbital RLV design has required substantial reconfiguration of existing technologies, and in some cases has called for research to create new technologies altogether. In addition, RLV design efforts have had to take into account the increased durability required for reusability of components, whereas ELVs need only function effectively for a single launch. Such technical challenges translate into considerable costs generally associated with orbital RLV development projects. Just as a reusable camera is more expensive to produce than a disposable one, it has proven more costly to attempt orbital RLV development than to refine ELV approaches. In sum, although the major reduction possible in operating costs makes orbital RLVs attractive, the difficulty and cost of development have continued to constrain progress toward orbital RLV implementation.

Clear testimony to the difficulty involved in orbital vehicle development is the fact that, of the many NASA and Air Force RLV programs that have been pursued, only the Space Shuttle has been produced. Further, the Space Shuttle is an example of a *partially* reusable launch vehicle (i.e., the external tank is expendable). Although an impressive achievement, the Shuttle does not meet all the operational goals of the Air Force or the private sector. NASA's Space Launch Initiative represents a major Government research effort to pioneer new technologies enabling development of more advanced, fully reusable vehicles, but fully operational vehicles based on these new technologies are not expected to appear until 2012 at the earliest. Commercial RLV development projects financed purely by the private sector represent other possible avenues for arriving at operational vehicles. Such commercial efforts generally attempt to reduce cost and technical difficulty by relying wherever possible on existing technologies rather than attempting to develop new technical capabilities. However, development costs have remained sufficiently high—and market opportunities have appeared sufficiently uncertain—to make it difficult for entrepreneurs to obtain the financing necessary to produce operational vehicles.

Image provided courtesy of NASA

The same governing dynamics that cause orbital ELVs to be larger than suborbital ELVs also apply to orbital and suborbital RLVs. In contrast to orbital RLVs, suborbital RLVs would be much cheaper both to develop and operate. Figure 8 displays sample orbital RLV and suborbital RLV concepts, graphically illustrating the considerable difference in size generally evident between the two approaches.

KST Astroliner KST LB-X

Figure 8. Size Comparison of Orbital and Suborbital RLVs

Images provided courtesy of Kelly Space and Technology (KST)

Furthermore, suborbital RLVs can have greater design margins (i.e., the amount of allowable increase in mass, volume, etc.) than orbital systems. This means, for example, that weight growth during the development period has much less of an impact on payload performance. In addition, these higher design margins allow off-the-shelf hardware (which is usually heavier) to be used, as well as allowing component redundancy to mitigate failures.

Image provided courtesy of NASA

Historical evidence for the feasibility of suborbital RLV development is readily available. Whereas a fully reusable RLV has yet to be developed, an operational suborbital RLV was developed over 40 years ago. In 1959, NASA conducted the first powered flight of its piloted, suborbital RLV, the X-15. The X-15 rocket program was a joint program conducted by NASA, the Air Force, the Navy, and North American Aviation for the purpose of researching hypersonic flight. By the conclusion of the program in 1969, the X-15 had achieved an unofficial world altitude record of 67 miles and a world speed record of Mach 6.7.

The X-15 program was extremely successful, reaching—and in some cases surpassing—its intended objectives. The reasons for not continuing this line of suborbital vehicle development did not involve any deficiencies in the program itself but rather concerned the larger context of U.S. government and commercial priorities. At the end of the 1960s, military efforts were for the most part focused on the refinement of the intercontinental ballistic missile (ICBM) fleet. NASA was increasingly concentrated on development of a manned *orbital* RLV—the Space Shuttle. In the commercial sector, suborbital market opportunities (e.g., microgravity research) were not yet sufficiently understood to stimulate much private sector interest.

However, private sector interest in suborbital market opportunities has changed significantly. As this report will proceed to demonstrate, potentially important national security, civil, and commercial uses of suborbital space are becoming increasingly evident. And, just as the perceived need for suborbital capabilities has increased, the technological tools available to vehicle developers have become increasingly sophisticated. If a piloted, suborbital RLV could successfully be developed and flown in 1959, it stands to reason that 40-plus years of technology evolution would render an expanded effort eminently feasible.

Beyond lower cost and simpler technology, another key factor working in favor of successful suborbital RLV development is entrepreneurial initiative. History has demonstrated that technology breakthroughs are often borne from the efforts of a few innovative individuals. In 1898, Samuel Pierpont Langley, secretary of the Smithsonian Institution, received a $50,000 grant ($1.042 million in FY02 dollars) from the U.S. War Department, as well as the personal backing of President McKinley, to develop a "flying machine" for passengers [ref 3]. The first piloted "Aerodrome" attempted a publicly advertised flight on

October 7, 1903, crashing into the Potomac River shortly afterwards. On December 8, 1903, a second attempt was made but was again unsuccessful.

In marked contrast to this well-financed initiative carried out by an acknowledged leader in the field, more humble efforts were afoot elsewhere. On December 17, 1903, just nine days after the second failed Aerodrome flight, Wilbur and Orville Wright successfully achieved a piloted, powered flight. Though the Wright Flyer I flew only 10 ft off the ground for 12 seconds, traveling a mere 120 ft, the aeronautical technology it demonstrated paved the way for passenger air transportation.

The success of the Wright brothers, armed with limited resources but drawing on creativity and hard work, has much in common with the proverbial "two guys in a garage" who helped spark the personal computer revolution. As such, stories like that of the Wright brothers serve as the battle cry for today's suborbital entrepreneurs.

The X-prize, initiated in 1996, is spurring private sector development of suborbital RLV systems. The X-prize is a $10 Million award for the first private sector team to build a piloted RLV, launch it to an altitude of 62 miles, carry the mass equivalent of 2 passengers, and repeat the event in less than 2 weeks. Additionally, the X-prize guidelines require development to be purely privately financed. The X-prize is fashioned after similar monetary prizes of the early days of aviation, such as the Orteig prize, which prompted Charles Lindbergh to cross the Atlantic in 1927. Much as the Orteig prize sparked rapid development in aviation, the goal of the X-prize is to spark rapid development in space transportation [ref 4].

Understanding the full significance of suborbital RLV development requires recognition not only of what suborbital RLVs may accomplish in their own right, but also of their significance as a transitional step towards orbital RLV development. In much the same way as the Wright Flyer I of 1903 led to incremental follow-on aircraft such as the WWII Spitfire, DC-3, F-86, and F-15, the vehicle that wins the X-prize will provide a technology "stepping stone" towards orbital RLV development. Additionally, development of operational RLVs could have a number of important benefits, such as:

- legitimization of space transportation as a private sector investment option, along with creation of long-term relationships between entrepreneurs and investors;
- growth of a profitable industry that could serve as a tax base, even after allowing for initial tax credits and/or tax holidays, to support later space research and exploration efforts;
- development of a more effective Federal and state space regulatory and policy framework, working out such issues as informed customer consent for assumption of greater risk and financial incentive structures; and
- development of the infrastructure linking vehicles to spaceports and the overall economy, such as through establishment of intermodal transport links (e.g., bringing people and cargo to and from a spaceport; connecting plane, rail, and highway routes to the spaceport).

PART 2

CURRENT ADDRESSABLE SUBORBITAL MARKETS

2 Current Addressable Suborbital Markets

This section addresses current suborbital missions that could potentially be served by a suborbital RLV. The current suborbital market consists mainly of DoD and NASA missions, and can be divided into three main categories:

- Missile Verification (DoD)
- National Missile Defense Tests (DoD)
- Sounding Rocket Research (NASA)
  - high-altitude and astronomical research
  - micro-gravity research and processing

The DoD's Missile Verification program performs roughly seven launches per year to confirm the systems operability of inventory missiles. Representative samples of missiles from various batches (e.g., Peacekeeper, Minuteman II and III) are removed from silos and shipped to Vandenberg Air Force Base for launch and verification. This is a periodic "check-up" of specific systems, and is not a market that could be penetrated by suborbital RLV systems. However, the remaining two suborbital market categories do provide opportunities, and are discussed below.

2.1 National Missile Defense Tests

The National Missile Defense program is the U.S. Government's effort to build a layered missile defense shield against "several tens" of incoming missiles potentially launched from a Third World or rogue state. This program has been conducted by the Missile Defense Agency (MDA) and its predecessor, the Ballistic Missile Defense Organization (BMDO). The National Missile Defense tests that have been carried out in the past few years include:

- Eleven Theater High Altitude Area Defense (THAAD) flight tests in the late 1990s from White Sands
- Four missile intercept tests from Vandenberg AFB and Kwajalein (2 launches per test) from 1999 through 2002
- Two tests of a new vehicle (Quick Reaction Launch Vehicle) in 2001 and 2002 from a new launch site in Kodiak, Alaska

Since the terrorist attacks of September 11, 2001, the National Missile Defense program has drawn increased funding and support. The program has been authorized for up to $8.2 billion for the 2002 fiscal year and projected program costs range from $60 billion for a limited defense involving land (radar, interceptors) and space (radar) components to $240 billion for a more extensive system incorporating, among other elements, sea based interceptors and high-powered air and space based lasers [ref 4,5].

The current concept has land, sea, air, and space based components. In the run-up to initial deployment, there will be an extensive test program carried out that will feature simulations, ground tests, risk reduction flights, and full-scale flight tests. A suborbital RLV would primarily address the risk reduction flight segment [ref 3]. Two key areas are the most promising and should be investigated further:

1. Testing of system components such as sensors
2. Release of simulated warheads for system tests

2.2 Sounding Rocket Research Activities

The DoD's Missile Verification and National Missile Defense programs represent a minor portion of U.S. suborbital missions. The majority of U.S. suborbital launches are conducted by the NASA Sounding Rockets Program Office out of their Wallops Flight Facility in Virginia. Figure 9 displays the 32-year launch history of sounding rocket missions conducted by NASA. These missions are for a variety of research objectives for NASA, universities, industry, international customers, the Department of Defense, and other investigators. Roughly 12% of these missions are conducted out of Wallops, while the remaining missions are performed at launch sites throughout the world (e.g., Greenland, Sweden, Canada). Figure 10 displays a breakdown of sounding rocket missions over the last 12 years, by launch site and by mission client. Figure 11 illustrates a breakdown of sounding rocket missions conducted by the NASA Sounding Rockets Program Office since FY96 by mission category.

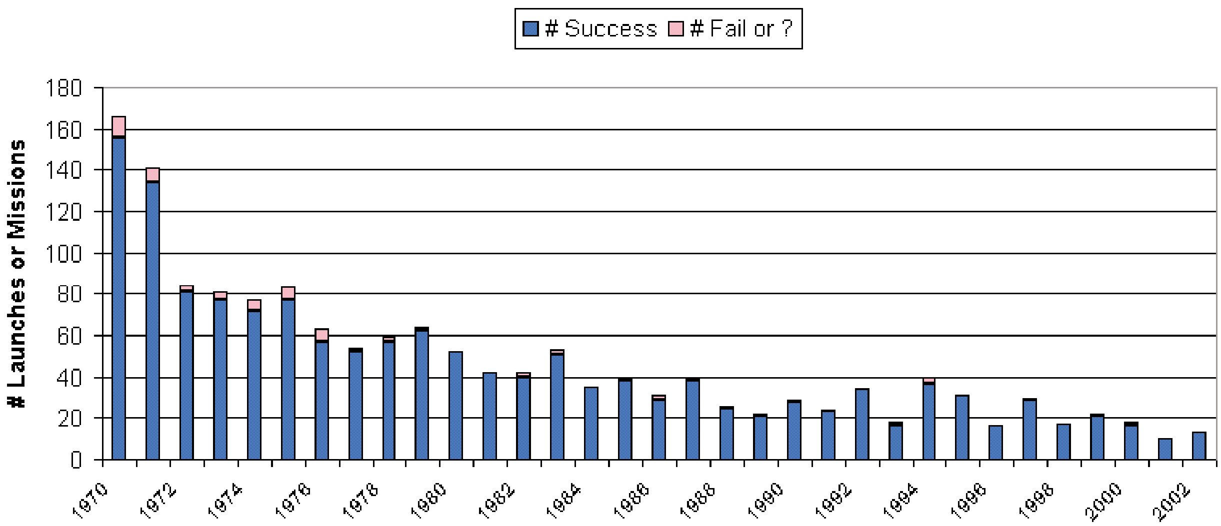


Figure 9. NASA Sounding Rocket Launch History

Data Source: Interview with NASA Sounding Rocket Program Office

2.2.1 High Altitude and Astronomical Research

As Figure 11 illustrates, the high altitude research missions (such as those for plasma physics, solar physics, and geo-space science), as well as the astronomy/astrophysics missions, represent a majority of the 106 sounding rocket launches conducted by the NASA Sounding Rocket Program Office since FY96. Sounding rockets (or any suborbital launch system) are able to reach a portion of the Earth's atmosphere (30-115 miles altitude) that is too high for research balloons and too low for orbiting satellites [ref 2].

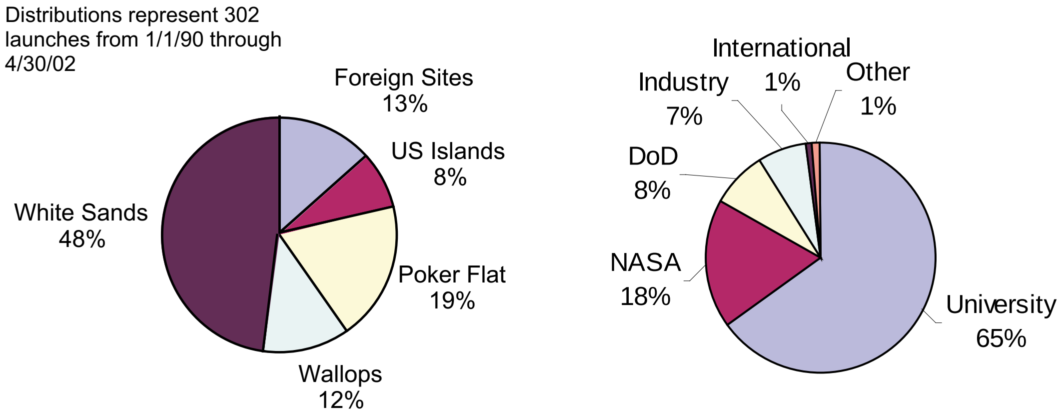


Figure 10. Breakdown of Sounding Rocket Launches by Launch Site and Organization

Data Source: Interview with NASA Sounding Rocket Program Office

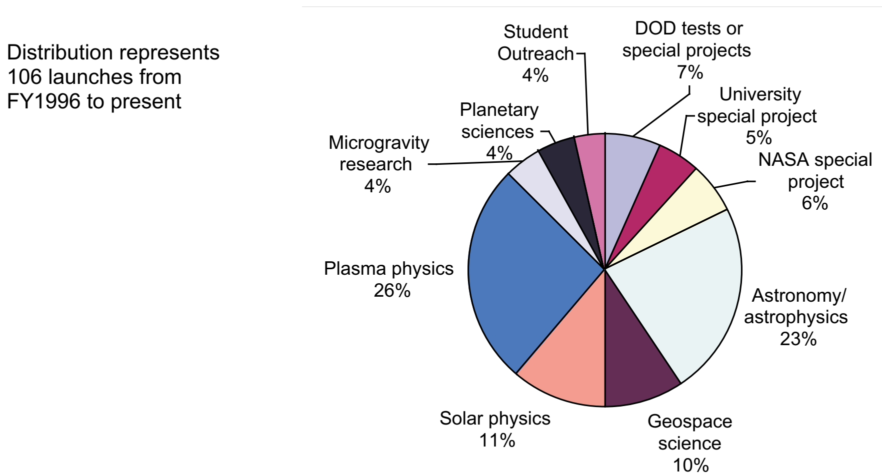


Figure 11. Breakdown of Sounding Rocket Launches by Mission

Data Source: Interview with NASA Sounding Rocket Program Office

Additionally, due to their high mission altitude, suborbital launch systems are able to observe astronomical, solar, and planetary radiation sources at wavelengths that are normally absorbed by the Earth's lower atmosphere. Suborbital launch systems provide a flexible, low-cost alternative to observation by orbiting telescopes.

2.2.2 Microgravity Research

While Figure 11 indicates that micro-gravity missions account for only 4% of the 106 missions, the micro-gravity market has high potential for future growth. The micro-gravity market has a wide variety of promising applications in pharmaceuticals, biology, materials processing, fluid physics, combustion, and component testing. The NASA Microgravity Program Office has indicated a number of research and development applications, many of which are currently served by sounding rockets, discussed below [ref 8,9].

- Protein Crystal Growth *(Pharmaceuticals)*

  Proteins carry out a variety of functions in the human body: transport of oxygen and other chemicals, cell and tissue growth, and immune system response. By better understanding a protein's structure and function in the human body, it is easier to develop new drugs and treatments that will interact with them. Crystals tend to grow larger and more uniform in micro-gravity, thus facilitating their analysis by X-ray diffraction. Even though crystal growth is benefited by a long micro-gravity exposure time (~ 1 week or more), crystals have been grown in the 5-20 minutes of micro-gravity available during a suborbital flight.

- Cell Function and Electrophoresis *(Biology)*

  Research aimed at understanding biological processes on a cellular level can be adapted to shorter duration testing times. A related area, electrophoresis, is the separation of biological components using a strong electrical field. There have been several successful sounding rocket flights carrying experiments in both of these areas.

- Development of New Materials *(Materials Science)*

  The micro-gravity environment allows the production of materials that are impossible to form on Earth. Two prominent examples are ZBLAN and Aerogel.

  - ZBLAN is a heavy metal fluoride glass that holds the theoretical prospect of producing fiber optic cables with 100 times greater capacity than today's silica-based ones. However, Earth-based processing has been unsuccessful due to the effect of gravity.
  - Aerogel is a highly porous silica based material that has an exceptional strength to weight ratio and insulating properties. It is foreseen for a wide variety of applications, one of which is windows. Unfortunately, non-uniform pore sizes in the material gives Aerogel a hazy blue color. It is suspected that production in micro-gravity could lead to a truly transparent substance.

- Semiconductor Production *(Materials Processing)*

  Crystalline materials such as silicon, germanium, and gallium arsenide can be produced in higher purity in the space environment due to the uniformity of the mixture (due to lack of buoyancy-induced convection) during formation. These have been produced on sounding rocket flights.

- Fluid Physics

  Experiments conducted in micro-gravity offer an environment free of gravity-induced phenomena such as sedimentation, buoyancy-induced convection, and hydrostatic pressure. The virtual absence of these forces, which drive most fluid behavior on earth, allows a better understanding of other fluid forces and mechanisms which, in turn, can lead to improvements in semiconductor crystal growth, design of structures to withstand disturbances such as earthquakes or floods, and power plant design. Research in these areas has been successfully conducted on suborbital sounding rocket flights.

- Combustion Science

  The absence of buoyancy-induced flow in micro-gravity leads to very different combustion behavior than on Earth. The absence of gravity allows scientists to better observe and understand other mechanisms of combustion such as fuel and heat transport and soot formation. This increased understanding can then be used to improve combustion processes on Earth, potentially leading to cleaner, more efficient, and more profitable operations.

- Component Research and Testing

  Ever since the beginning of the space program, micro-gravity testing facilities have been used to test the operation of new concepts for space systems. In the U.S., this activity began in drop towers in order to test components for the ballistic missile and civil exploration efforts. The current sounding rocket program provides a low-cost testbed for scientific techniques, instrumentation, and spacecraft technology that will eventually be applied and flown on satellite missions. For example, NASA satellite missions such as COBE, CGRO, ASTRO-2, UARS, SOHO, and TRACE have been enabled by technology and techniques developed through NASA's suborbital program.

It is worth noting that during the development phases of the Space Shuttle and the International Space Station (ISS), numerous studies were conducted concerning the potential commercial applications, including those areas listed above, of the micro-gravity space environment. However, though numerous commercial micro-gravity missions have flown on-board the Shuttle, the number of applications has fallen short of projections. Hindsight indicates that the findings on the benefits of the micro-gravity environment spurred efforts to produce the same or similar substances in earth-bound research facilities. Further, the lack of a streamlined process and protocol for flying commercial missions has deterred potential customers and limited repeat clients. Though the research areas listed above have been examined over the past 20 years on the Shuttle and are planned research activities for the ISS, suborbital RLV operators could position themselves to capture a significant share of the short-duration micro-gravity market. To do this, suborbital RLV operators will need to learn from the Shuttle experience (e.g., by maintaining competitiveness with earth-bound facility development, by streamlining the experiment integration process, by reaching satisfactory accommodations to proprietary data rights issues).

PART 3

EMERGING SUBORBITAL MARKETS

3 Emerging Suborbital Markets

There are several national security, civil government, and commercial markets that are not currently being served by today's sounding rockets, but could rapidly grow with the emergence of operational suborbital RLVs. Although additional market research would do much to augment understanding of the character and potential of these markets, sufficient information is available to describe them in general terms.

For suborbital RLV concepts being designed for dual-use capability (i.e., the same vehicle type used by both U.S. Government and commercial customers), the development of multiple markets (i.e., military, intelligence, civil, commercial) might significantly lower customer costs. With the expansion of such markets, and a consequent increase in flight rate for dual-use-design RLVs, fixed operating costs could be amortized over more flights. This would translate into lower costs to the government customer (since commercial products and services supplied to the government are regulated by profit caps), and potentially the commercial customer as well. Additionally, if the growth of government and commercial markets contributes to a significant increase in vehicle production, manufacturing economies of scale would contribute to lowering the cost per vehicle—an advantage to both government and commercial customers. Significant cost reduction would allow greater national security and civil benefits to be achieved with limited budgetary resources.

3.1 Military Surveillance and Commercial/Civil Earth Imagery

The ability to fly a high-resolution camera at extremely high altitudes along border regions creates a valuable military reconnaissance asset. Whereas surveillance satellites' orbits are fixed, suborbital RLVs could provide "pop up" reconnaissance capability, a fleet of suborbital RLVs could provide hourly surveillance of areas of interest. Furthermore, since the imagery could be provided to the Commander in Charge with the landing of the RLV instead of through data relay connections, this type of surveillance method would not impose any bandwidth requirements on an already saturated battlefield communication network. This market has been strongly promoted by TGV Rockets. Figure 12 below presents a sample region that could be examined on a suborbital trajectory from launch at the indicated site.

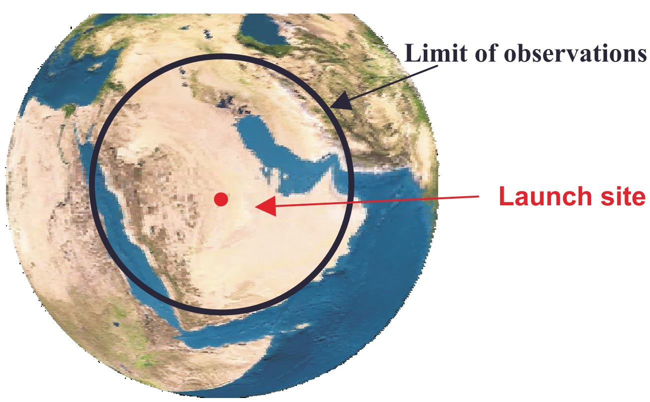


Figure 12. Region of Observation for Suborbital Surveillance

Image provided courtesy of TGV Rockets, www.internationalspace.com, and www.fourmilab.ch.

In much the same way that suborbital RLVs could be surveillance gap-fillers for the military, they could also be gap-fillers for commercial and civil government earth imagery (i.e., “remote sensing”) needs. There are many areas of the world not over-flown by commercial or civil remote sensing satellites, but for which suborbital RLVs, given their high altitude surveillance capability over specific targets, could provide imagery. Customers might include international banks, insurance companies, oil companies, and multinational corporations.

3.2 Fast Package Delivery

Fast Package Delivery (FPD) refers to the transportation of freight over transoceanic distances in a period of hours and provides a potential market opportunity for RLVs. Suborbital RLVs can potentially enter this market. However, in order to be economically viable, the range capability of suborbtial vehicles needs to approach at least transatlantic distances (e.g., New York to Frankfurt), and preferably transpacific distances (e.g., Los Angeles to Singapore) [ref 9, 12]. An assessment of the range capability of the suborbital RLVs discussed in this report was beyond the scope of this project. Therefore, this report presents Fast Package Delivery as a potential market opportunity. Further analysis is required to determine if the vehicles can achieve the range required to enter this market.

Examining key issues associated with Fast Package Delivery can assist those who might wish to explore in more detail the potential for suborbital vehicles to enter this market. Business worldwide has acknowledged the emergence of a global economy, and the need has arisen for the delivery of urgent packages over transoceanic distances in a short period of time. Federal Express, which owns the majority of the international express delivery market, has indicated that a substantial portion of their international revenue comes from priority cargo [ref 9, 10]. Rapid transport of packages is advantageous for several reasons. Time to market can often mean the difference between success and failure. For some products, because of high value and short shelf life, added transportation cost for decreased delivery time may be more beneficial than extensive warehousing costs. Further, items of a perishable nature, such as organs and biological specimens, demand rapid delivery. Yet, even with current technology, express delivery to Asia, for example, still takes 72 hours. Because of greater speed and consequently reduced flight duration, a suborbital (or orbital) RLV might potentially provide the capability to capture a large section of the rapidly growing international express delivery market. However, as noted earlier, this depends on the vehicle’s achievable range.

Further examination of current Fast Package Delivery market structure reveals two modes of service: scheduled and on-demand service [ref 9]. With scheduled service, the vehicle takes off at set departure times, servicing various hubs in the network. Though market volume for this type of service may be stable, service time is offset by elements of the delivery process that restrict benefits of faster flight times, such as time between flights. For example, a high priority item that needs to be at its destination in 2 hours may have to wait 3 hours for the next scheduled flight. Therefore, RLVs are not well suited for scheduled Fast Package Delivery service, since the minimization of flight time impacts a small portion of the total delivery time.

The other mode of Fast Package Delivery service is on-demand service [ref 9]. This is similar to the way in which charter aircraft operate, and the vehicle departs at customer request, or “on-demand.” The market volume is less than that for scheduled service (since it only serves one customer at a time), but the urgency of the cargo attracts a much higher service charge. RLVs are much better suited for on-demand Fast Package Delivery service, since the minimization of flight time impacts a significant portion of the total delivery time.

Commodities whose transport would benefit from an on-demand Fast Package Delivery system are numerous. As noted previously, perishables such as biological specimens and organs gain much more serviceability with faster transport. The heart, for example, can only survive outside the body for 4 hours [ref 12]. A long range, quick transport vehicle would significantly increase the service radius. Additionally, time sensitive items such as critical parts for overseas assembly lines would be well served by a Fast Package Delivery system. Intel, for instance, loses approximately $200,000 (FY97) for every hour the production line is non-operational [ref 9,10]. According to the 1994 Commercial Space Transportation Study (CSTS), the cargo industry generally considers it acceptable to spend 3% to 6% of the total aggregate value of a product on transportation cost [ref 12]. Thus, a significant amount of money could be afforded for transportation for items such as precious stones and electronic circuitry, which range between $100,000 and $10,000,000 in collective quantities. Further, for items of high aggregate cost value and short shelf life, the added cost for significantly decreased delivery time would be advantageous over the alternative warehousing costs [ref 9,10].

3.3 High Speed Passenger Transportation

High-speed passenger transportation, otherwise known as point-to-point passenger transportation, refers to the ferrying of passengers between two locations (or two points on the Earth) at speeds greater than those offered by current transportation systems. High-speed passenger transportation is very similar to Fast Package Delivery, except that the cargo is human. Suborbital RLVs may be capable of providing such a service. However, further analysis is required to determine if suborbital vehicles can achieve the range required to enter this market. For sufficient market capture, suborbital RLVs would need to service those routes for which flight time constitutes a significant portion of the total transportation time.

Similar to Fast Package Delivery, high-speed passenger transportation has two modes of service, scheduled and charter. However, scheduled passenger transportation service involves less pre-flight processing than Fast Package Delivery scheduled service. For example, there is no package drop-off or package pick-up. (A package can sit for six hours at a drop-point, then travel four hours to the airport while all the drop-points are visited.) Thus, while suborbital RLVs are not well suited for scheduled Fast Package Delivery service, there is a potential market opportunity for scheduled high-speed passenger transportation.

Suborbital RLVs could also provide high-speed charter service. Such flights would be less frequent than scheduled service flights, but the revenue per seat would be much higher. To be economically viable, chartered high-speed passenger transportation service would need to resolve the issue of deadhead return (i.e., the return of the vehicle to the launch site without any revenue-producing cargo).

There are a number of issues that must be addressed for a suborbital RLV to be able to serve a scheduled or chartered high-speed passenger transportation market. Those issues include, but are not limited to, integration with conventional airports, integration with the current air traffic control system, passenger safety, and land overflight (e.g., noise).

3.4 Media, Advertising and Sponsorship

Media is one of the largest industries in the world, and space-related entertainment, advertising, and sponsorship have been looked to as an integral component of any private or public-private partnership space business model. The size of this market is critical in the closure of many space business plans.

3.4.1 Film and Television

The recent success of true story space-themed films such as Apollo 13 suggests that a feature on a successful private suborbital space vehicle may have a market. For example, in September 2000, NBC paid between $35 and $40 million to broadcast Mark Burnett's (creator of "Survivor") next reality series "Destination Mir." Burnett had teamed with MirCorp, who would provide a 10-day trip aboard the Russian Space Station Mir. The reality series was not intended to show actual space footage but rather to follow contestants through Space Camp until one was selected for the 10-day excursion to space.

Reality television has been a tremendous success story over the last 5 years, and ideas such as "Destination Mir" could easily be adapted to the suborbital space environment. Further, a trip to suborbital space could be a platform for educational films such as the popular IMAX series.

3.4.2 Product Endorsement

In 1962, John Glenn picked up a Minolta Hi-Matic self-winding camera to use on his history-making orbital flight. Glenn's purchase, although unintentional, was one of the first acts of space product endorsement. This was to be followed by NASA's adoption of the Omega Speedster watch in 1965 and the Fisher Space Pen in 1968. Aboard the Space Shuttle, M&M candies and IBM Thinkpad computers have had their image bolstered by use in orbit.

All product endorsement does not have to be unintentional, however. In 1985, Coca-Cola and Pepsi spent hundreds of thousands of dollars on developing special pressurized cans to allow their product to be consumed in space. More recently, the Final Frontier beef jerky company and an Israeli milk company have paid or donated their products to be consumed in space.

Another niche segment of this market is the sale of "flown-in-space" items. Over the years, thousands of items have flown in space, including postcards, flags, mission patches, and even Lego toys to be given away in a contest. Carrying these items onboard suborbital flights could provide a small additional revenue stream.

Although significant precedents have already been set through product endorsements and direct advertising since the 1960's, a true quantifiable market has yet to be established in this area. Even considering that the time in flight will be less than that for a space shuttle or space station mission, product endorsement represents a market segment for the developers of suborbital RLVs.

3.4.3 Advertising, Branding, and Sponsorship

Similar to the situation seen today in the space tourism segment, the Russian space program, driven largely out of financial need, has opened the door to a wide array of ideas for space-based advertising. Logos for companies such as Pizza Hut and Kodak have been painted on the sides of Proton rockets and the Mir Space Station. Television commercials have been filmed on board the Mir and ISS for Pepsi, Radio Shack, and an Israeli milk company. Although NASA has yet to adopt a favorable position towards space-based advertising, a privately funded vehicle would be able to consider a wider range of options.

From sporting events to classical music to volunteer housing construction, corporate sponsorship is part of a $25 billion annual industry. Sponsorship is used to achieve a variety of different objectives. Sponsoring a sporting event with a high audience share allows a company to have a longer exposure time for their brand at a lower cost than with traditional commercial spots. Other companies choose to sponsor events that associate the brand with a particular lifestyle or demographic group, whether it is through beach volleyball or professional golf.

Sponsorship of the suborbital vehicle concepts under development could achieve some of these benefits through association (e.g., young, adventure-oriented demographic) or by leveraging media coverage of the flight or any television coverage of the race between the various teams attempting to win the X-prize.

3.5 Space Tourism

Space Tourism is a concept that has long fascinated the world. Following the success of the 1968 Stanley Kubrick film “2001: A Space Odyssey,” Pan Am began taking reservations for the first commercial voyage to the moon without specifying either date or cost or asking for a reservation fee. Mostly a publicity stunt, the list nevertheless grew to thousands of names before Pan Am stopped taking reservations.

It is now 2002, and space tourism has become a reality. In April of 2001, California businessman Dennis Tito paid a sum approaching $20 million for a ride to the International Space Station and a stay that lasted 2 weeks. The following year, South African Internet millionaire Mark Shuttleworth made the same trip, reportedly for a similar price. A number of other candidates have also been actively pursuing this opportunity, including teen pop-music star Lance Bass as well as space enthusiast and former NASA official Lori Garver.

In May of 2002, the public opinion research firm Zogby International released the results of a Space Tourism poll commissioned by Futron Corporation [ref 1]. The commission was part of Futron’s NASA-funded study known as ASCENT (Analysis of Space Concepts Enabled by New Transportation). The Zogby survey polled 450 people throughout the United States over a 3-week period beginning January 6, 2002. Each participant was required to have a minimum annual income of at least $250,000, and a net worth of about $1 million. This discriminator was a key aspect of the poll, since past public opinion polls on space tourism have not accounted for whether or not the respondent could afford the trip. Nineteen percent of the 450 interviewed indicated they would be willing to pay the $100,000 per seat price for a 15-minute ride to suborbital space. The margin of sampling error was +/- 4.7%. This represents an encouraging market for suborbital space tourism, considering that in 2000 there were 7 million people globally with a net worth of $1 million or more [ref 2].

Two adventure tourism companies, Incredible Adventures and Space Adventures, have already responded to public demand. Formed in 1993, Incredible Adventures offers a wide range of adventure travel, from high-speed racing boat trips, to shark diving adventures, to cosmonaut training, to flights aboard the Russian MiG. Incredible Adventures has now expanded these adventure opportunities to include rides aboard a suborbital RLV. They have formed joint marketing agreements with candidates such as Vela Technology and Pioneer Rocketplane.

Their competitor, Space Adventures, has begun accepting reservations for a $98,000 trip to suborbital space. About 100 reservations have been received thus far. In March of 2002, US Airways and Space Adventures announced an exclusive business agreement whereby US Airways' Dividend Miles members will have the opportunity to redeem frequent flyer miles for a suborbital space trip. Founded in 1997, Space Adventures offers a wide range of experiences, including cosmonaut training, Russian MiG flights, and trips to major launch sites. Space Adventures assisted with and facilitated the flights of space tourists Dennis Tito and Mark Shuttleworth.

3.6 Space Diving

Another adventure market that might be served by a suborbital RLV is a concept being proposed by Canadian Arrow called “Space Diving.” Space diving is essentially sky diving at extremely high altitudes. During the Space Race of the 1960's, NASA conceived of several "space parachutes" as orbital escape systems for its astronauts. These space parachutes included personal retro-rockets and conical drag skirts or inflatable cones to protect the astronaut during reentry. With such types of space suits, thrill seekers could jump from extremely high altitudes. Today, this quest for high altitude jumps is readily apparent. An organization know as Stratoquest is currently involved in sending pilot Cheryl Stearns on a jump at an altitude of 130,000 ft to break the record of 102,800 ft set by Colonel Joseph W. Kittinger in 1960 [ref 4]. Stratoquest is using a high-altitude balloon to carry Stearns to 130,000 ft, which is the maximum altitude for balloons. A "space dive" from a suborbital RLV would more than double the 130,000 ft target of the Stratoquest organization.

PART 4

SUBORBITAL RLVs IN DEVELOPMENT

4 Suborbital RLVs in Development

4.1 Overview and Approach

There are a number of suborbital RLVs currently under development, both within the U.S. and abroad. The intent of each of these developers is to provide enhanced capabilities for the 30-100 mile altitude space environment. This study examined 14 concepts, 10 U.S. and 4 international. Data were obtained from extensive telephone and email interviews and are presented *as reported*. The information was not altered, and each company signed a letter of agreement testifying to the accuracy of the information presented for its particular suborbital RLV concept.

Additional information on each of the concepts can be found in the Appendix, which also includes the management biographies for each of the companies. A significant portion of this project was devoted to collecting and organizing the data in the Appendix, and the reader is encouraged to visit that section of the report. This section has been prepared to highlight the information found in the appendix.

Since this study was for the U.S. Department of Commerce, the emphasis was on domestic suborbital RLVs, but a few international development programs were examined to provide benchmarks. Of the international companies interviewed, most would consider re-locating to the U.S. for operations if a re-location would benefit their business case.

The list of 10 U.S. concepts is not comprehensive, and several suborbital RLV concepts were not included in the study. This was because either 1) the concept did not appear sufficiently mature, or 2) company representatives were not available for comment. These companies should be recognized for their efforts however, and are presented in Table 1.

The 14 suborbital RLV concepts examined in this study are displayed in Table 2. Space Launch Corporation has been listed as a company with a suborbital RLV "Under Study," as opposed to "In Development," because they are not *focusing* on suborbital markets. Instead, Space Launch Corporation is focusing on the micro-satellite launch market. However, their vehicle, the SLC-1, could be reconfigured as a suborbtial vehicle (the SLC-S1). The SLC-S1 is not discussed in this section, but is included in the Appendix.

4.2 Discussion of Concepts

Table 2 presents the 14 suborbital concepts examined in this study. Tables 3-5 describe the system specifications for each of the suborbital concepts, and are categorized by the RLV method of take-off and landing.

Table 1. U.S. Suborbital RLV Concepts Not Included in Study

Company	**Vehicle**
Advent Launch Services	Advent
Aero Astro, LLC	PA-X2
Cerulean Freight Forwarding Company	Kitten
Discraft Corporation	(Unnamed)
Funtech Systems	Aurora
Scaled Composites	Proteus (space transport version)
Vela Technologies	Space Cruiser

Table 2. Suborbital RLV Concepts Included in Study

Company	**Vehicle**
Armadillo Aerospace	Armadillo Aerospace Suborbital Rocket
Andrews Space and Technology	AS&T Suborbital Aerospaceplane
Kelly Space and Technology	Sprint and LB-X
Lone Star Space Access	Cosmos Mariner
Pan Aero	SabreRocket
Pioneer Rocketplane	Pathfinder XP
Starcraft Boosters, Inc.	Starbooster4
TGV Rockets	Michelle-B
XCOR	Xerus
*Space Launch Corporation	SLC-S1
**Bristol Spaceplanes (UK)	Ascender
**Canadian Arrow (Canada)	Canadian Arrow
**Myasishchev Design Bureau (Russia)	Cosmopolis C-21
**Starchaser Industries (UK)	Thunderbird

**concept is under study*
***non-U.S. development programs*

The performance capability, development cost, development schedule, and development status of the various systems is presented in Table 6 and Table 7. A few important points regarding these tables:

1. Many companies are focusing on suborbital space tourism, and when asked the non-human payload capability of their system, were unable to provide a specific number for the mass. In such cases, the figure of 220 lbs/passenger was applied to the characteristic “payload capability to 100 km.”
2. The “Price per Flight” should not be confused with cost per flight, which may be considerably lower than the price charged in the marketplace. Many companies used Space Adventures’ $98,000 per passenger price tag when providing this information. This figure was rounded to $100,000 for simplicity.
3. The development costs vary widely. In addition to this variance being associated with different designs, the variance also arises because *not every company uses the same cost models or same assumptions in estimating development cost*. As such, this figure should be considered cautiously. Further investigation into the cost-estimating assumptions is necessary before these numbers can be accurately compared. However, these numbers do provide a starting point.

Table 3. Horizontal Take-off and Horizontal Landing Suborbital RLV Concepts

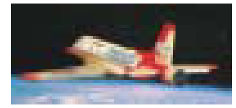
						
Company	Andrews Space and Technology	Bristol Spaceplanes	Lone Star Space Access	Pan Aero	Pioneer Rocketplane	XCOR
Vehicle	Suborbital Aerospaceplane	Ascender	Cosmos Mariner	SabreRocket	Pioneer XP	Xerus
No. Crew	Proprietary	2	Proprietary	1	2	1
Length	95 ft	44.9 ft	100 ft	43.75 ft	46 ft	40 ft
Wingspan	85 ft	25.9 ft	87 ft	44.43 ft	26 ft	26 ft
Gross Weight	271,000 lbs	9,900 lbs	136,000 lbs	26,200 lbs	32,250 lbs	Proprietary
Airframe	New	New	New	Converted Sabre 40	New	New
Air-Breathing Engine	Proprietary	Williams-Rolls FJ44	Proprietary	PW JT12A-8	J85-15 or J85-21	None
No. A/B Engines	Proprietary	2	2	2	2	0
Rocket Engine	Proprietary	PW RL-10	Proprietary	Microcosm	New	XCOR engine
Rocket Engine Propellants	RP-1/LOX	Hydrogen/LOX	JP/LOX	Kerosene/LOX	Kerosene/LOX	Alcohol/LOX or Kerosene/LOX
No. Rocket Engines	Proprietary	1	3	7	1	4

Table 4. Assisted Horizontal Take-off and Landing Suborbital RLV Concepts*

			
Company	Myasishchev Design Bureau	Kelly Space	Kelly Space
Vehicle	Cosmopolis C-21	Eclipse Sprint	LB-X
Assist Vehicle	M-55X	F-4 Phantom	F-4 Phantom
No. Assist Vehicle Crew	1	2	2
No. LV Crew	1	(remotely piloted)	1
LV Landing Method	Glide and parachute	Glide	Glide
Length	26.25 ft	Proprietary	Proprietary
Wingspan	17.72 ft	Proprietary	Proprietary
LV Gross Weight	6,000 lbs	Proprietary	Proprietary
Rocket Engine	solid rocket motor	TBD	KST developed engine
Rocket Engine Propellants	information not available	LOX/RP-1	KST developed (patent pending) monopropellant
No. Rocket Engines	1	1	1

*Space Launch Corporation is not included in this table. See Appendix.

Table 5. Vertical Take-off Suborbital RLV Concepts

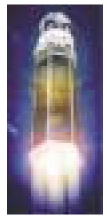
					
Company	TGV Rockets	Canadian Arrow	Starchaser Industries	Starcraft Boosters, Inc.	Armadillo Aerospace
Vehicle	Michelle-B	Canadian Arrow	Thunderbird	Starbooster 4	Armadillo Aerospace Suborbital Rocket
No. LV Crew	1	1 to 2	1	0	1
LV Landing Method	Rocket-powered vertical landing	Ram-air ballute and parachute	Parachute and inflatable airbags	Horizontal glideback landing	Rotorblades
Length.	37.4 ft	53.5 ft	80 ft	34 ft	Undetermined
Diameter	7.9 ft	5.4 ft	5.2 ft (maximum diameter, not including strap-ons)	3.7 ft	Undetermined
LV Gross Weight	61,327 lb	Proprietary	44,267 lbs	16,300 lbs	7,000 lbs
Rocket Engine	Aero-Astro PA-X-30K	Proprietary	Starchaser Industry Hybrid Engine	AFRL pressure-fed engines	Armadillo Aerospace engine
Rocket Engine Propellants	Kerosene/LOX or Alcohol/LOX	Alcohol/LOX and Solid Propellant	HTPB/LOX	Kerosene/LOX	Hydrogen Peroxide
No. Rocket Engines	6	1 (first stage) + 4 (second stage)	1 + 4 strap-ons (first stage) + 1 (second stage)	2	1

Table 6. U.S. Suborbital RLV Program Characteristics*

Company	Andrews Space and Technology	Lone Star Space Access	Pan Aero	Pioneer Rocketplane	XCOR	Kelly Space and Technology	Armadillo Aerospace	Starcraft Boosters, Inc.	TGV Rockets
Vehicle	Suborbital Aero-spaceplane	Cosmos Mariner	SabreRocket	Pioneer XP	Xerus	Eclipse Sprint & LB-X	(not named)	Starbooster4	Michelle-B
Price per Flight	Less than $1,000,000	$2M-$4.5M	N/A (for X-prize only)	$200,000-$400,000	$100,000	TBD	$60,000	$750,000	$1M
Payload to 100km Altitude	14,000 lbs	24,880 lbs	330-440 lbs	440-880 lbs	220 lbs	2,000 lbs	440 lbs	3,800 lbs	2,200 lbs
No. Passengers	Proprietary	4	0	2 to 4	1	0 and 2	2	0	0 to 5
Development Cost	$250M	$125M	$2.4M	$10 - $20M	$10M	$30M	$1M	$115M	$50M
Development Schedule	3.5 years	5 years	Less than 1 year	2.5 -3.5 years	3 years	2.5 yrs	1.5 years	4 years	2 years
Development Status	Vehicle is at conceptual level.	Completed preliminary design & feasibility studies. Configuration is selected.	Completed preliminary design & feasibility studies. Configuration is selected.	6 configurations being considered. Will down-select when funding arrives.	Vehicle is at conceptual level.	LB-X is at a level between concept and preliminary design. The Sprint is at the conceptual level.	Currently in construction phase. "Design-as-we-build" approach.	In progress under AFRL contract.	Vehicle is at conceptual level.

*Space Launch Corporation is not included in this table. See Appendix.

Table 7. International Suborbital RLV Program Characteristics

Company	Bristol Spaceplanes	Canadian Arrow	Myasishchev Design Bureau	Starchaser Industries
Vehicle	Ascender	Canadian Arrow	Cosmopolis C-21	Thunderbird
Price per Flight	$200,000	Proprietary	$200,000	$100,000 - $250,000
Payload to 100km Altitude	440 lbs	220-440 lbs	440 lbs	440 lbs
No. Passengers	2	1-2	2	2
Development Cost	$50M-$100M for prototype, another $200-$300M for fully operational vehicle	Proprietary	$12M	$5M
Development Schedule	3 years for prototype, + 3-4 yrs for fully operational vehicle	1.5 years	2.5 yrs	2 years
Development Status	Completed feasibility assessment (under ESA contract)	Currently in construction	Configuration is selected, full-scale prototype developed and unveiled in March 2002	2 yrs away from human launch

PART 5

SUMMARY

5 Summary

This report has discussed suborbital RLV market opportunities, as well as suborbital RLV development efforts.

There are a number of current and emerging suborbital market opportunities upon which suborbital RLV systems can capitalize. Current addressable suborbital markets are served mostly by expendable sounding rockets, and include national missile defense tests, as well as high-altitude, astronomical, and micro-gravity research missions. Each of these presents a viable opportunity for suborbital RLVs. Further, there are a number of new markets that could emerge with the advent of an operational suborbital RLV. These emerging markets include military surveillance, commercial/civil earth imagery, fast package delivery, high-speed passenger transportation, media, advertising, sponsorship, space tourism, and even “space diving.”

For suborbital RLV concepts being designed for dual-use capability (i.e., the same vehicle type used by both U.S. Government and commercial customers), the development of multiple markets (i.e., military, intelligence, civil, commercial) might significantly lower customer costs. With the expansion of such markets, and a consequent increase in flight rate for dual-use-design RLVs, fixed operating costs could be amortized over more flights. This would translate into lower costs to the government customer (since commercial products and services supplied to the government are regulated by profit caps), and potentially the commercial customer as well. Additionally, if the growth of government and commercial markets contributes to a significant increase in vehicle production, manufacturing economies of scale would contribute to lowering the cost per vehicle—an advantage to both government and commercial customers. Significant cost reduction would allow greater national security and civil benefits to be achieved with limited budgetary resources.

Suborbital RLV development is being pursued by a number of entrepreneurial organizations. Whereas orbital space transportation development has traditionally taken a “one big step” approach, these organizations have elected to take an incremental approach, beginning with a suborbital system and gradually transitioning to an orbital capability. This step-by-step approach is similar to the way aircraft have developed since the Wright brothers flight of 1903. Since suborbital RLVs are much less complex than orbital systems, the goal of these entrepreneurial organizations is more attainable.

While the success or failure of the entrepreneurial companies presented in this report cannot be predicted, and a full feasibility study is beyond the scope of this report, suborbital RLVs do present a much simpler design challenge than orbital RLVs (as witnessed by the success of the suborbital X-15 program in 1959). The X-prize competition, a $10 Million reward to the first RLV company to demonstrate passenger transport to suborbital space, has been a significant motivator for this entrepreneurial community. In much the same way as the Wright Flyer I of 1903 led to incremental follow-on aircraft such as the WWII Spitfire, DC-3, F-86, and F-15, the vehicle that wins the X-prize will provide a technology “stepping stone” towards orbital RLV development. In addition to providing such a catalyst, an operational suborbital RLV will pave the roadway for appropriate RLV regulatory, insurance, and financial policies and strategies.

PART 6

REFERENCES

6 References

6.1 Introduction

1. NASA, "Sounding Rocket Program [online]," Wallops Flight Facility, available URL: (http://www.wff.nasa.gov/pages/soundingrockets.html), [last accessed in July 2002]
2. Isakowitz, S., Hopkins, Jr., J., Hopkins, J., International Reference Guide to Space Launch Systems, AIAA, 3rd edition, 1999.
3. Anderson, John, Jr. Introduction to Flight, 3rd edition. McGraw-Hill, 1989.
4. X-Prize, "What's the X-Prize", available URL: (http://www.xprize.org), [last accessed in July 2002]

6.2 Current Addressable Suborbital Markets

1. NASA, "NASA Sounding Rocket Science [online]," Goddard Space Flight Center, available URL: (http://rscience.gsfc.nasa.gov/srrov.html), [last accessed in May 2002]
2. NASA, "Sounding Rocket Program [online]," Wallops Flight Facility, available URL: (http://www.wff.nasa.gov/pages/soundingrockets.html), [last accessed in July 2002]
3. Gore, P., Rubery, M., Reiman, T., Bolt, B., Langford, A., "National Missile Defense (NMD) Test Program, NTIS ADA355746, 1998.
4. Hellman, Christopher, "The Costs of Ballistic Missile Defense [online]," Center for Defense Information, available URL: (http://www.cdi.org/hotspots/issuebrief/ ch5/index.html), [last accessed in May 2002].
5. Sietzen, F., "Missile Defense, Options and Obstacles," Aerospace America, May 2002, pp. 30-35.
6. Corrêa, F. de A. Jr., Moraes, P. Jr., "Aspects of High Performance Sounding Rockets as Platform for Microgravity Experiments," 51st International Astronautical Conference, Oct. 2-6, 2000, Paper IAF-00-J.2.09, Rio de Janeiro (2000).
7. Lundquist, C.A., et. al., "Suborbital Rocket Program for Commercial Microgravity Research," 43rd Congress of the International Astronautical Federation, Aug. 28 - Sept. 5, 1992, Paper IAF-92-0981, Washington D.C. (1992).
8. NASA, "Microgravity Research Program [online]," Marshall Space Flight Center, available URL: (http://www1.msfc.nasa.gov/NEWSROOM/background/facts/ microgravity.html), [last accessed in May 2002].
9. NASA, "Microgravity Research Disciplines [online]," Marshall Space Flight Center, available URL: (http://mgnews.msfc.nasa.gov/db/understanding_ug/ understanding_ug), [last accessed in May 2002].

6.3 Emerging Suborbital Markets

1. Zogby International, "News", available URL: (http://www.zogby.com/news/ReadNews.dbm?ID=577), [last accessed in July 2002]

2. Merrill Lynch, Gemini Consulting, “World Wealth Report 2000,” 2000.

3. Canadian Arrow, “Space Diving”, available URL: (http://www.canadianarrow.com/spacediving.htm), [last accessed July 2002]

4. Stratoquest, “Statoquest Web Site [online],” available URL: (http://www.stratoquest.com), [last accessed in June 2002].

5. Pearlman, R., “A Brief History of Space Marketing [online],” Space.com, available URL: (http://www.space.com/news/spaceagencies/space_market_ 010531-1.html), [last accessed in June 2002].

6. Incredible Adventures, “Incredible Adventures - Adventure Travel Around the World,” available URL: (http://www.incredible-adventures.com), [last accessed in June 2002].

7. Space Adventures, “Space Adventures: Suborbital Space Flight,” available URL: (http://www.spaceadventures.com/suborbital/index.html), [last accessed in June 2002].

8. IEG Inc., “IEG’s Complete Guide to Sponsorship,” 2001.

9. Martin, J. “Exploring Fast Package Delivery from a Systems Perspective”, Master of Engineering Thesis, Massachusetts Institute of Technology, 1999.

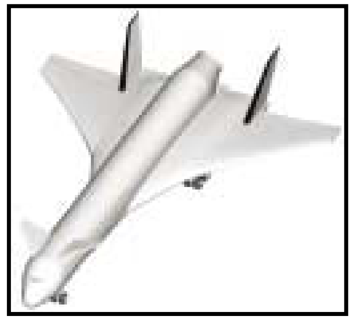
10. Martin, J., Palmer, K., Chan, M., et al., "Fast Package Delivery: Commercial Application of a Hypersonic Airbreathing Vehicle," *Defense and Civil Space Conference and Exhibit-1998*, AIAA #98-5261.

11. Andrews, D.G., Dunn, M.J., Rubeck, M. “Transportation Requirements for the Fast Freight Market”, The Boeing Company, September 1997.

12. Commercial Space and Transportation Study Final Report, Commercial Space Transportation Alliance, April, 1994.

APPENDIX A.1

DOMESTIC SUBORBITAL RLVs IN DEVELOPMENT



Vehicle: AS&T Suborbital Aerospaceplane
Developer: Andrews Space & Technology (AS&T)
Launch Price: Less than $1M
No. Passengers: Proprietary
Payload to 100km: 14,000 lbs
Contact Info: Livingston Holder
(206) 342-9934 x 200

General Description

The AS&T Suborbital Aerospaceplane operates similar to an aircraft, taking off and landing horizontally with existing jet engines, and operating out of, and integrating with, conventional airports and the current air traffic control system. The AS&T Suborbital Aerospaceplane will be able to serve suborbital and orbital launch needs. The large passenger compartment can be converted to a payload bay to house rocket upper-stages or other military payloads. The design is currently proceeding under company funds with support from Vought Aircraft and Aerojet.

Concept of Operations

The vehicle takes off horizontally like an airplane under jet-power. Jet and rocket propellant are fed to the spaceplane while in subsonic flight via aerial refueling. At a given altitude, the rockets are ignited and accelerate the vehicle to Mach 6.5 and an altitude of 75 miles (120 km). The vehicle then returns to its point of origin under jet-power.

Cost and Schedule

Development Cost	~$250M
Development Schedule	3.5 yrs

Performance

Payload Capability	14,000 lbs pressurized cargo
Price per Flight	Less than $1M

Logistics

Turnaround Time	1 day
Potential Launch Sites	Any facility with conventional runway

Configuration-Airframe

Length	95 ft.
Wingspan	85 ft.
Gross Weight	271,000 lbs (Takeoff)
Propellant Weight	170,000 lbs (LOX/RP-1)
Propellant Type	LOX/RP-1 and JP-8

Configuration-Engine

	Jet Engine	**Rocket Engine**
Type of Propulsion	Proprietary	Proprietary
Engine	Proprietary	Proprietary
Number of Engines	Proprietary	Proprietary
Sea Level Thrust	Proprietary	Proprietary

Growth Options

The AS&T Aerospaceplane, using an upper stage, is capable of placing small payloads in low earth orbit, so no enhancements are required to achieve orbital capability.

ANDREWS SPACE AND TECHNOLOGY MANAGEMENT BIOS

Marian Joh, Chairperson & CEO
Marian Joh is co-founder as well as Chairperson of the Board and the Chief Executive Officer of Andrews Space & Technology. In this capacity, she oversees the corporation's business, contracts, and finance activities and provides direction for the budget, policy, and business strategies for the company. Due to the fact that Andrews Space & Technology is a relatively new company, she is currently focused on suitably staffing the Board, developing initiatives for additional company financing, establishing and implementing corporate procedures, and servicing existing engineering support contracts.

Prior to coming to Andrews Space & Technology, Ms. Joh was the Vice President of Sheinrock Advisory Group. In this capacity she was responsible for working with clients to determine corporate business strategy and develop strategic initiatives to improve their position in the marketplace. She developed financial models, implemented corporate policies and procedures, and established new business initiatives for a number of companies including Lockheed Martin (for VentureStar), Bell Semiconductor, Tornado Development Inc., and others.

Prior to her work at Sheinrock, Ms. Joh was the lead financial analyst at Kistler Aerospace Corporation, which raised approximately $500 million to develop a fully reusable commercial launch vehicle. At Kistler, Marian developed and maintained the corporation's financial model and justified Kistler's financial assumptions to investors during four PPMs. Ms. Joh was also instrumental in developing Kistler's Business Plan and was a key member of the initial financial team that raised over $200 million in private equity.

Dana Andrews, Chief Technology Officer
Dr. Dana Andrews joined Andrews Space & Technology and Chief Technology Officer in March 2000, after almost 34 years with The Boeing Company. During his last two years at Boeing, Dr. Andrews was located in Southern California as Director of Reusable Launch Systems for the Boeing Phantom Works, where he oversaw the Boeing TSTO RLV, Future X, Military Space Plane, and Solar-Thermal Orbital Transfer Vehicle (SOTV) programs. Prior to that he was in the Boeing Aerospace group in Seattle where his responsibilities included: oversight of the Boeing Air-Launch Studies, Chief Engineer for the Boeing side of the McDonnell/Boeing team X-33/RLV, initiation and management the Boeing team for the Commercial Space Transportation Study (CSTS), Program Manager for the 1990-1991 BMDO SSTO Study, Function Manager for the Aerodynamics for the Boeing Aerospace Group, Boeing Habitation module Manager for the International Space Station Program in Huntsville, AL, and Program Manager for the Aero-Assisted Orbital Transfer Vehicle (AOTV). Dr. Andrews also had an extensive background with The Boeing Company in aircraft design and advanced propulsion.

Dr. Andrews currently serves as Chairman of the Space Transportation Committee of the International Astronautics Federation (IAF), which is the international organization of national societies for astronautics. He is the past chairman of the Space Transportation Technical Committee of the AIAA, and a member of both the IAF Interstellar Exploration and the AIAA Advanced Propulsion technical committees. He has published approximately 30 papers dealing with space transportation devices and is the co-inventor of the magnetic sail (Magsail) with Robert Zubrin.

Jason Andrews, President
Mr. Andrews spent more than three years at Kistler Aerospace Corporation before leaving to co-found Andrews Space & Technology. He began at Kistler in 1995 as their Launch Vehicle Performance Analyst and is credited with sizing the K-1 launch vehicle. In September 1995, he was given the additional task of Propulsion Project Engineer, managing propulsion contractors Pratt & Whitney and GenCorp Aerojet through the requirements definition and preliminary design phases. In February 1997, Mr. Andrews was promoted to Design Integration Manager where he was responsible for developing, managing and maintaining configuration control over the detailed design of the K-1 launch vehicle. This task required integrating and managing the activities of Kistler's contractor team, which included Northrop Grumman Corporation, Lockheed Martin, GenCorp Aerojet, Irvin Aerospace, Allied Signal, Draper Labs, and Oceaneering Aerospace. In June 1998, Mr. Andrews was given the task of K-1 Vehicle Two Project Manager, where he was responsible for all aspects of Kistler's second K-1 launch vehicle. In November 1998, he left Kistler Aerospace to co-found Andrews Space & Technology.

Livingston L. Holder, Jr., Vice President Space Systems
Mr. Holder joined Andrews Space & Technology in January 2002 as Vice President, Space Systems, where he is responsible for all of the company's space systems design, development, and service activities.

Mr. Holder worked for The Boeing Company for 14 years. During that time, his responsibilities included Senior Manager, Advanced Information Systems, Advanced Space and Communications for Boeing Phantom Works, leading the Spacecraft and Launch Segments of the RESOURCE21 Program, Program Manager then Chief Engineer of Boeing's Aviation Information Systems (now Connexion by Boeing), lead for Boeing's Future Space Transportation organization, Program Manager of the Sea Launch Program during its initial development, member of Boeing's Space Station Team, lead for the development of requirements for the design and construction of crew systems, later managing the development and coordination of all international and domestic interfaces, and finally lead for the Habitation Module team.

Prior to coming to The Boeing Company, Mr. Holder served in the United States Air Force. His assignments there included participation in the Titan III launch crew, classified satellite programs for the Office of the Secretary of the Air Force, and training and qualifying as a Manned Spaceflight Engineer and Space Shuttle Payload Specialist.
Mr. Holder is currently the Chairman of the Commercial Space Transportation Advisory Committee (COMSTAC) to the Department of Transportation's Federal Aviation Administration. He served Boeing's Historically Black Colleges and Universities/Minority Institutes Committee, and was Boeing's Executive Focal to Alabama A&M for the past ten years.

Vehicle:	Cosmos Mariner
Developer:	Lone Star Space Access
Launch Price:	$2-$4.5M
No. Passengers:	4
Payload to 100km:	24,880 lbs
Contact Info:	Norman LaFave 281-880-8926

General Description

The Cosmos Mariner is to be used primarily as an inexpensive option to launch small payloads to low earth orbit and for suborbital space tourism.

The Cosmos Mariner operates similar to an aircraft, taking off and landing horizontally with existing jet engines, and operating out of, and integrating with, conventional airports and the current air traffic control system. The Cosmos Mariner is powered by two jet engines and three rocket engines, enabling it to reach altitudes of 62 miles (100 km).

Concept of Operations

The Cosmos Mariner takes off from a coastal airport with its two jet engines. After 15-20 minutes, the vehicle will be cruising at approximately 40,000 ft. and Mach 0.8. It then performs an initial pitch up maneuver and stabilizes for rocket ignition. The rocket burns for approximately 130 seconds, after which the vehicle will be at Mach 7 and an altitude of 38 miles (61 km). The vehicle continues to coast upwards, reaching apogee above 62 miles (100 km) about 100 seconds later. The vehicle returns to the airport under the power of its jet engines.

Cost and Schedule

Development Cost	$125 M
Development Schedule	5 years (1 year for finalizing design issues, 2-3 years for construction, 1 year for testing).

Performance

Payload Capability	4 passengers/ 24,880 lbs
Price per Flight	$2M - $4.5M

Logistics

Turnaround Time	Goal of 1 - 2 weeks, initially longer to allow for careful inspection of vehicle
Potential Launch Sites	Venezuela, New Jersey, South Texas, Oklahoma have expressed interest. Goal is to use any conventional runway

Configuration-Airframe

No. Crew	Proprietary
Length	100 ft
Wingspan	87 ft
Gross Weight	136,000 lb (120,000 lb at rocket ignition)
Propellant Weight	Proprietary
Propellant Type	JP/LOX

Configuration-Engine

	Jet Engine	**Rocket Engine**
Type of Propulsion	Turbofan	Rocket
Engine	Existing, proprietary	Existing, proprietary
Number of Engines	2	3
Sea Level Thrust	25,000 lb	90,000 lb

Growth Options

The Cosmos Mariner is capable of placing small payloads in low earth orbit, so no enhancements are required to achieve orbital capability.

LONESTAR SPACE ACCESS MANAGEMENT BIOS

Norman J. LaFave, Chief Executive Officer
Dr. LaFave founded Lone Star Space Access Corporation (LSSA) in 1995 as Dynamica Research, a company performing a variety of work on spacecraft and spacecraft mission design and analysis for NASA and other customers. Dr. LaFave has 18 years of experience doing state of the art research in physics, computer modeling, aerospace, computers, and electro-optics for NASA, the Federal Aviation Administration, the United States Air Force and the United States Navy. He has also been a project manager for a major system acquisition for the Federal Aviation Administration. During his career, Dr. LaFave has published papers in several journals and technical publications on a variety of subjects. Most recently he has been an independent contractor for the Lockheed Martin Corporation as an expert in aerodynamics and simulation for the NASA Space Shuttle and Space Station programs. Dr. LaFave has a Bachelor of Science in Physics and Mathematics from Carnegie Mellon University and a Ph.D. in Physics from The University of Texas at Austin. He has been an Air Force Weapons Laboratory Fellow and the recipient of a National Research Council Associateship.

Robert Todd, President
Mr. Todd serves as President of Lone Star Space Access Corporation (LSSA) and as such handles all day-to-day operations of the company. Mr. Todd completed his undergraduate work at the University of Texas at Austin where he received a Bachelor of Arts degree in Latin American Studies, and he was awarded his Doctorate of Jurisprudence degree from South Texas College of Law. Mr. Todd has a distinguished legal and business record in Texas where he participates in many civic and community endeavors. Those endeavors include currently serving as a third-term Houston City Councilman, Board Member of the Clear Lake Economic Development Foundation and Board Member of the Houston Livestock Show and Rodeo. He is a life-long aviation enthusiast and has been part of the LSSA team for four years.

Shannon Brown, Chief Financial Officer
Ms. Brown brings over 18 years of financial experience to Lone Star Space Access. She is currently employed as a financial manager at Compaq Computer Corporation. Her previous employment was with IBM Corporation. She has experience with strategic planning and forecasting, budgeting, capital, inventory planning and control, management, and pricing. She received her Masters in Business Administration in accounting from The University of Texas at Austin and a Bachelor of Arts in Economics from Colby College.

Dan Tuckness, Chief Technical Officer
Dr. Tuckness is currently the head of the Aerospace and Mechanical Engineering Department at the University of Texas at Arlington. He is an expert in spacecraft/mission analysis and design, trajectory analysis, statistical estimation theory, guidance and navigation systems, GPS systems, and atmospheric flight dynamics. His current research involves Mars and Lunar Landing Navigation suite design and analysis, the use of space sextants for spacecraft navigation, GPS/INS integration to subdue tracking errors in

control loops, and studies of orbital stability using Poincare surfaces of section. Previously, he was a lead engineer at Lockheed Engineering and Sciences Company supporting NASA where he lead a team performing guidance, navigation, and control studies, system development, and simulation development for the Mars Rover Sample Return mission, Common Lunar Lander mission, Mars Global Network mission, and the Lifesat mission. He has published numerous papers in technical journals and conference proceedings. Dr. Tuckness has a Bachelor of Science in Physics and Mathematics from Southeastern Oklahoma State University and a Master of Science and Ph.D. in Aerospace Engineering from The University of Texas at Austin. He has received several awards for his technical work and his teaching.

Penny Todd, Chief Marketing Officer
Ms. Todd brings 15 years of experience in marketing, public relations, and advertising to Dynamica Research. A native Houstonian, her areas of expertise include new product development from the design stage through market development. As owner of a marketing company, and through associations with firms such as DBG&H Inc. and Ogilvy and Mather, she has represented industries including healthcare, real estate, economic development, food and beverage, natural gas, plastics, and sports fitness. Ms. Todd graduated Magna Cum Laude from Southwest Texas State University with a Bachelor of Arts in Marketing.

Vehicle:	SabreRocket	
Developer:	Pan Aero, Inc.	
Launch Price:	Undetermined	
No. Passengers:	0	
Payload to 100km:	330-440 lbs	
Contact Info:	Len Cormier (202) 347-5060	

General Description

Development of the \$2.4M SabreRocket is intended primarily for winning the \$10M Xprize purse. Winning proceeds, and leverage from the Xprize sponsorship and publicity, would be applied towards follow-on concepts such as a small orbital launch system or to the suborbital Space Cruiser (for which PanAero would partner with Vela Technology Development, Inc.) which will carry 6 passengers. The SabreRocket would still be available for non-passenger suborbital missions.

The SabreRocket operates similar to an aircraft, taking off and landing horizontally with existing jet engines, and operating out of, and integrating with, conventional airports and the current air traffic control system. The SabreRocket is a converted Sabre 40 aircraft, and is powered by two jet engines and seven rocket engines, enabling it to reach altitudes of 62 miles (100 km). The SabreRocket will carry one pilot. However, the SabreRocket will not carry passengers, but rather the mass equivalent of 2 passengers (330-440 lbs) to meet the rules of the Xprize.

Concept of Operations

The SabreRocket takes off from a conventional airport with its two jet engines, climbing to an altitude of 11 km and a speed of Mach 0.8. The rocket engines are then ignited, accelerating the vehicle to Mach 2.97 and reaching an altitude of 50km at a 60° flight-path angle. After the rockets have completed their burn, the vehicle coasts upwards to 100 km. The vehicle returns to the airport under the power of its jet engines.

Cost and Schedule

Development Cost	\$2.4 M
Development Schedule	Less than 1 year

Performance

Payload Capability	No passengers/330-440 lbs
Price per Flight	N/A (The SabreRocket is for the Xprize only)

Logistics

Turnaround Time	Less than 1 week, possibly less than 1 day
Potential Launch Sites	Any conventional runway

Configuration-Airframe

No. Crew	1
Length	43.75 ft
Wingspan	44.43 ft
Gross Weight	26,200 lb
Propellant Weight	13,200 lb
Propellant Type	Kerosene/LOX

Configuration-Engine

	Jet Engine	**Rocket Engine**
Type of Propulsion	Turbojet	Rocket
Engine	PW JT12A-8	Microcosm 5 klb engines
Number of Engines	2	7
Sea Level Thrust	3,300 lbs	5,000 lb

Growth Options

The SabreRocket will be followed by the suborbital SpaceCuiser, for which Pan Aero has partnered with Vela Technologies. The SpaceCruiser will carry 6 passengers.

Both the SabreRocket and SpaceCruiser are stepping-stones towards an orbital capability. Pan Aero has multiple orbital vehicle concepts that they are evaluating, such as a small orbital launch system and the much larger Millenium Express.

PANAERO MANAGEMENT BIOS

Len Cormier, President

Mr. Cormier has dedicated most of his efforts during the past 40 years to the pursuit of lower cost access to space. He began his career in the space business at the National Academy of Sciences in 1956 and at NASA headquarters in 1959. In the early and mid-1960s he was project engineer for space transportation systems at the Los Angeles Division of North American Aviation, Inc. After that he worked as a project engineer and program manager for Fighter Systems at North American-Rockwell. Mr. Cormier formed his own company in 1967 to pursue commercial space launch consulting, which he has continued for the past thirty years with a wide variety of aerospace consulting projects. From 1943 to 1967, Mr. Cormier served as a Naval Aviation cadet, Navy fighter pilot, and executive officer of an ASW patrol squadron on active duty and in the Naval Reserve. Len holds a BA in physics from the University of California. Len speaks Russian and is proficient in Pascal. Len was a charter member and a re-appointed member of the Dept. of Transportation's Commercial Space Transportation Advisory Committee (COMSTAC). Presently, Mr. Cormier is president of PanAero, Inc. and Third Millenium Aerospace, Inc. PanAero, Inc. is participating in the X-Prize and has recently been awarded a contract by DARPA for the RASCAL concept, with Coleman as a prime contractor.

Team

PanAero believes in ad hoc program management, and is project oriented. Various experts throughout the country are utilized as needed for each project.

Vehicle:	Pioneer XP
Developer:	Pioneer Rocketplane
Launch Price:	$200,000-$400,000
No. Passengers:	2-4
Payload to 100km:	440-880 lbs
Contact Info:	Mike Scardera (805) 693-8222

General Description

The Pathfinder XP operates similar to an aircraft, taking off and landing horizontally with existing jet engines, and operating out of, and integrating with, conventional airports and the current air traffic control system. The Pathfinder XP is powered by two jet engines and two rocket engines, enabling it to reach altitudes of 66 miles (106 km).

Concept of Operations

The Pathfinder XP takes off from a conventional airport with its two jet engines. At a given altitude, the rocket engines are ignited, and the vehicle climbs towards its peak trajectory. About four minutes of 0.0001 g or less are available at the peak of the trajectory. The vehicle returns to the airport under the power of its jet engines.

Cost and Schedule

Development Cost	$10 M - $20 M
Development Schedule	2.5–3.5 years, depending on configuration

Performance

Payload Capability	2-4 passengers/ 440-880 lbs
Price per Flight	$200,000-$400,000

Logistics

Turnaround Time	1 week or less
Potential Launch Sites	Initially Oklahoma. Goal is to use any conventional runway.

Configuration-Airframe

No. Crew	2
Length	46 ft
Wingspan	26 ft
Gross Weight	32,250 lb
Propellant Weight	7,765 lb Kerosene/10,873 lb LOX
Propellant Type	Kerosene/LOX

Configuration-Engine

	Jet Engine	**Rocket Engine**
Type of Propulsion	Turbojet	Rocket
Engine	J85-15 or J85-21	In development
Number of Engines	2	2
Sea Level Thrust	4,000 lb	~12,000 lb

Growth Options

Pathfinder XP will lead to the Pathfinder vehicle, which will deliver payloads to low earth orbit.

PIONEER ROCKETPLANE MANAGEMENT BIOS

Merrill A. "Tony" McPeak, Chairman of the Board
General McPeak served 37 years in the Air Force, in all capacities of command, culminating in Chief of Staff. Prior to becoming service chief, he led the Pacific Air Forces, supervising activities in Hawaii, Alaska, Japan, Korea, the Philippines, and Guam. As Chief of Staff, he was responsible for a combined force of over 850,000 people serving at approximately 1,300 locations in the United States and overseas. With the Joint Chiefs of Staff, he served as adviser to the Secretary of Defense, the National Security Council and the President. He headed the Air Force during a period of intense U.S. overseas military involvement, including Desert Shield and Desert Storm as well as active operations in Somalia, Bosnia, Rwanda and the Caribbean. At the same time, he conceived and executed the most far-reaching reorganization of the Air Force in its 50-year history and is widely regarded as having created a more streamlined modern service. As a career fighter pilot, he flew 269 combat missions in Vietnam and 200 aerobatics exhibits with the "Thunderbirds." He has accumulated more than 6500 flying hours in over 50 types of military aircraft. General McPeak holds a degree in Economics from San Diego State College and a Master's Degree from George Washington University in International Affairs. General McPeak was the 1993 winner of the Thomas White Space Trophy, sponsored by the National Geographic Society. He also received the Hartinger Award for outstanding military space achievement.

Mitchell Burnside Clapp (Founder), CEO, President
Mitchell Burnside Clapp holds a Masters Degree in Aeronautics and Astronautics from the Massachusetts Institute of Technology and is a graduate of the U.S. Air Force Test Pilot School. The author of numerous technical papers on various subjects in the area of space transportation, Burnside Clapp was the inventor of the concept of aerial propellant transfer to enable horizontal takeoff-horizontal landing, single stage to orbit spaceplanes. He led the design effort at the U.S. Air Force's Phillips Lab that developed the first such design for this type of vehicle, the "Black Horse" rocketplane. He then was responsible for presenting this concept to numerous high level decision making bodies and study groups throughout the Air Force, resulting in the strong recommendation by the Air Force's "Spacecast 2020" study that a trans-atmospheric rocketplane be developed for military purposes. Burnside Clapp has flown over forty different types of military and civilian aircraft, and is the only person outside the former McDonnell Douglas trained to fly the DC-X single stage research demonstration vehicle.

Charles Lauer (Founder), Vice President of Business Development
Mr. Lauer is the President of Peregrine Properties in Ann Arbor, Michigan and is responsible for arranging financing for over $100 million in successful business developments. While earning his income from Earth-based business deals, Lauer has spent over a decade researching potential business opportunities in space. He was an advisor to the NASA-aerospace industry Commercial Space Transportation Study. Mr. Lauer is a consultant to Boeing and NASA on commercial space station development.

Michael P. Scardera, Senior Systems Engineer

Mr. Scardera graduated with a Bachelor's in Aeronautics and Astronautics from MIT in 1985 and with a Master's Degree from the University of Maryland in 1986. During his educational tenure, Mike Scardera performed engineering on several space system laboratory projects including a space shuttle flight experiment, which flew in 1985. He performed finite element analysis work as an adjunct engineer prior to military service. During 11 years of U.S. Air Force service, Mike Scardera worked in several technically challenging areas. He was considered a premiere analyst with USAF Navstar Global Positioning System (GPS) operations. Mike's GPS performance was so impressive, he became the youngest technical manager leading the team responsible for the GPS navigation service. Under his leadership, GPS accuracy and availability significantly improved. Following GPS, Mike worked in several classified projects and programs in a technical leadership role. Mike's last job prior to coming to Pioneer Rocketplane was as a Space and Missile Center program manager/system engineer responsible for several system concept, design, and technology studies. In this job, Mike was also involved in future space architecture and military spaceplane activities. Mike Scardera has won several awards for innovative design and is in Who's Who of America's Scientists and Engineers.

Vehicle: Xerus
Developer: XCOR
Launch Price: $100,000
No. Passengers: 1
Payload to 100km: 220 lbs
Contact Info: Jeff Greason
(661) 824-4714

General Description

XCOR's suborbital vehicle is a horizontal takeoff and horizontal landing single stage vehicle. The vehicle utilizes a cluster of four 2,000 lb thrust rocket engines, enabling it to reach altitudes of 62 miles (100 km). The vehicle does not use jet engines. For suborbital missions, the vehicle will take off and land from the same site.

Concept of Operations

XCOR's suborbital vehicle takes off horizontally using its four rocket engines. The vehicle returns to the launch site for an unpowered landing.

Cost and Schedule

Development Cost	$10 M (includes production of 2 vehicles)
Development Schedule	3 years (1.5 years to build, 1.5 years to test)

Performance

Payload Capability	1 passenger/ 220 lbs
Price per Flight	$100,000

Logistics

Turnaround Time	Less than 1 day
Potential Launch Sites	Mojave, Oklahoma, or other remote airports

Configuration-Airframe

No. Crew	1
Length	40 ft
Wingspan	26 ft
Gross Weight	Proprietary
Propellant Weight	Proprietary
Propellant Type	Alcohol/LOX or Kerosene/LOX

Configuration-Engine

Type of Propulsion	Rocket
Engine	Scaled up version of XCOR's 400 lb rocket engines, which have been tested
Number of Engines	4-5
Sea Level Thrust	2,000 lb

Growth Options

XCOR's suborbital vehicle can be fitted with an expendable upper stage to serve the low earth orbit micro-satellite market.

XCOR MANAGEMENT BIOS

Jeff Greason, Co-founder, Chief Executive Officer and President
Jeff was a technical manager at Intel for 10 years, developing a lower cost BiCMOS technology that became the basis for the Pentium product line. After Intel, he spent two years managing the propulsion team at the Rotary Rocket Company. There he built a world-class development team and led key technical efforts in rocket engines. He holds 18 U.S. patents and has a BS degree in engineering from California Institute of Technology.

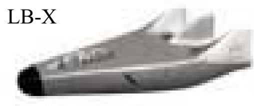
Dan DeLong, Co-founder, Chief Engineer
Dan DeLong has 25 years of experience developing prototype and one-of-a-kind hardware. He was a co-founder of Rotary Rocket and developed rocket engine hardware for Kistler's K-0 vehicle. Mr. DeLong spent 10 years working on Space Station life support hardware and development projects for Boeing, and Space Shuttle payload hardware for Teledyne Brown. From 1974 through 1983, he developed military and commercial life support hardware for Westinghouse, and manned and unmanned underwater vehicle systems design for Perry Oceanographics in FL. Mr. DeLong has a BS degree in engineering from Cornell University.

Randy Baker, Chief Financial Officer
Randy Baker has 23 years experience in business and brings a wealth of experience with start-up organizations. As CFO of Looksmart (NASDAQ:LOOK), he oversaw the financial and business aspects from its inception in 1996 through its highly successful IPO. Ten years experience with Big 5 accounting firm KPMG supports his knowledge and experience. Mr. Baker holds a BA degree in Business Studies, majoring in Accounting and Marketing, from Royal Melbourne Institute of Technology.

Vehicle: Sprint and LB-X
Developer: Kelly Space & Technology, Inc. (KST)
Launch Price: TBD
No. Passengers: 0 and 2
Payload to 100km: 2,000 lbs
Contact Info: Michael J. Gallo
(909) 382-5642

Sprint

LB-X



General Description

Kelly Space and Technology's suborbital RLV's operate similar to an aircraft, and use a patented tow-launch technology for take-off. KST's family of RLVs are designed to operate out of, and integrate with, conventional airports and the current air traffic control system. KST's two stand-alone suborbital RLV concepts are the Eclipse Sprint and the LB-X. The Sprint is a remote piloted, rocket powered single stage vehicle designed to meet the requirements of the academic and scientific communities in providing sounding rocket services for micro-gravity research and development. The LB-X is a rocket propelled, manned (pilot and two passengers) vehicle, designed to meet the X-Prize requirements of safely carrying a pilot and two passengers on a round trip to 100 kilometers (62 miles) and repeating the mission within two weeks.

Concept of Operations

The Sprint and LB-X concept of operations involves KST's patented tow launch technology and utilizes a McDonnell Douglas F-4 Phantom to tow the launch vehicle from a conventional runway to the launch location at a given altitude. At this altitude, the Sprint or LB-X's rocket engines are ignited, the towline is released, and the vehicle climbs to an altitude of approximately 300,000 feet. The Sprint/LB-X then returns, performing an unpowered landing.

Cost and Schedule

Development Cost	$30 M (includes production of 3 suborbital vehicles)
Development Schedule	2.5 yrs

Performance

Payload Capability to 100km	2,000 lbs
Price per Flight	TBD

Logistics

Turnaround Time	Less than 2 weeks
Potential Launch Sites	Any facility with conventional runway

Assist Aircraft

Type RLV	Sprint/ LB-X
Tow Aircraft	McDonnell Douglas F-4 Phantom
Type of Assist	Tow-launch
No. Crew	2
Aircraft Gross Weight	62,000 lbs
Aircraft Empty Weight	41,500 lbs
Aircraft Length	63 ft
Aircraft Wingspan	39 ft
Engines	GE J79 after-burning turbojets
Number of Engines	2

RLV Configuration-Airframe

Type RLV	Sprint	LB-X
Pilot	Remote	1
Passengers	N/A	2
Length	Proprietary	Proprietary
Wingspan	Proprietary	Proprietary
Gross Weight	Proprietary	Proprietary
Propellant Weight	Proprietary	Proprietary
Propellant Type	LOX/ RP-1	KST developed (patent pending) monopropellant

RLV Configuration-Engine

Type RLV	Sprint	LB-X
Engine	TBD	KST developed engine
Number of Engines	1	1
Sea Level Thrust	20,000-30,000 lbs	20,000-30,000 lbs

Growth Options

Development of the suborbital system will lead to the Astroliner and other orbital RLVs capable of delivering small to heavy payloads to orbit.

KELLY SPACE AND TECHNOLOGY MANAGEMENT BIOS

Michael S. Kelly, Chairman of the Board and CEO
Prior to founding KST in April of 1993, Michael S. Kelly was the Director of Engineering for TRW's Space Launch Services Operations. Mr. Kelly's association began with the TRW Ballistic Missile Division, a division contracted by the U.S. government to develop and support the nation's strategic ballistic missile program. During this time, Mr. Kelly managed and led significant portions of the Air Force expendable launch vehicle programs such as the Peacekeeper and Small Intercontinental Ballistic Missile (ICBM).

As TRW's Director of Engineering, Mr. Kelly had lead responsibility for design and development of TRW's Launch Services Organization, which included commercial launch service operations. This organization was formed under the direction of Mr. Daniel Goldin, Vice President of TRW at the time, who until very recently served as the Administrator of NASA. Mr. Kelly wrote the patent for this TRW family of ground-launched vehicles. A similar concept, called the Athena, has been developed and is now operated by Lockheed-Martin Corporation. After Mr. Goldin left for NASA, TRW decided to cease all launch vehicle development and discontinued this launch program, leaving a major void in the small- to mid-size payload launch market. Mr. Kelly recognized this significant market niche and resigned from TRW to form KST in pursuit of this portion of the space launch industry. Mr. Kelly focused KST's research on developing innovative RLV system design concepts, which led to the Eclipse launch solution, on which Mr. Kelly was issued a U.S. patent.

Since the start of the Company, Mr. Kelly has testified before both Houses of Congress on FAA licensing of launch and re-entry of reusable vehicles. He holds a key role on the Commercial Space Transportation Advisory Committee (COMSTAC), chairing the RLV Working Group, which advises the FAA on all regulatory policy affecting licensing and operation of these vehicles. He has become a nationally recognized leader in the emerging launch industry.

It has always been Mr. Kelly's vision that the Company's purpose is to serve as a vehicle for creating wealth based not only on the exploitation of space as a place of business, but on application of the technology involved in the exploitation of space to terrestrial problems. He does not see the Company primarily as a developer of space transportation systems, but rather as a fountainhead of beneficial technology. In this regard, Mr. Kelly has applied his knowledge of space systems to develop several key energy-related technologies in the areas of biomass waste processing and gasification, non-toxic gasoline additive and power storage devices. Mr. Kelly holds several patents and is dedicated towards implementation of his technological accomplishments for the benefit of mankind.

Michael J. Gallo, President and Chief Operating Officer

Mr. Gallo began his professional career as an Officer in the United States Air Force, managing Military Airlift Command facility design and operations at Norton Air Force Base in San Bernardino, California. He designed and managed a variety of base facility and airfield construction projects and directed mobility deployment forces to establish remote airfields and base operations worldwide. In 1984, Mr. Gallo left the Air Force to join TRW's Ballistic Missiles Division, providing support to the USAF in the development and deployment of the Peacekeeper and Small ICBM Weapon Systems. He managed the Systems Design and Cost organization responsible for supporting system design, acquisition, cost management, budget and finance activities. Mr. Gallo developed key computerized cost estimating, budgeting, and analysis models that are still in use today. As a result, cost estimates for the $22 billion Peacekeeper program were within 1.5% of the actual total program cost at completion - one of the few government programs completed under budget and ahead of schedule.

In 1989, Mr. Gallo was selected by TRW as a member of the core team to establish the TRW Launch Services Organization and manage program operations and project control activities for the TRW family of low-cost launch vehicles. This organization was formed under the direction of Mr. Daniel Goldin, then Vice President of TRW, now recently retired as Administrator of the National Aeronautics and Space Administration (NASA). Mr. Gallo was the Director of Program Control, leading financial analysis, cost estimating, budgeting, risk assessment, scheduling, configuration control, data management, computer analysis, product reliability, quality assurance and safety analyses for the launch system program.

In 1993 Mr. Gallo co-founded Kelly Space & Technology, Inc. (KST), a commercial RLV and space technology development company located at the former Norton Air Force Base, where he currently serves as President and Chief Operating Officer, overseeing the day-to-day operations of the Company. As an implementer, Mr. Gallo provides leadership to the development and commercialization of the Company's technology and currently serves as one of three Managers for Global Energy Systems, LLC, a KST subsidiary formed to implement its energy-related lines of business.

Mr. Gallo provides leadership to the commercial, civil and military space community as the Chairman of the California Space Authority (CSA), an organization that serves as the space policy advisor to the Secretary of the California Technology, Trade and Commerce Agency and represents the State of California on all space-related issues. Mr. Gallo also serves as the Arrowhead Section Chairman of the American Institute of Aeronautics and Astronautics (AIAA) and Chairman of the County of San Bernardino Community Action Board, which provides management and fiscal oversight to the County's Community Services Department. He is also the Vice President of the Economic Development Division of the San Bernardino Area Chamber of Commerce.

Peter E. Jonker, President, Global Energy Systems, LLC (KST Energy Subsidiary)
Mr. Jonker is an energy industry professional with a 30-year, consistent record of solid accomplishment and a broad range of experience in all phases of regulatory and governmental affairs. He is a recognized expert in environmental, health and safety issues and is a highly successful negotiator with officials at all levels of government. He is a seasoned communicator and public speaker with an un-blemished reputation as both lawyer and chemical engineer, with high credibility among his industry peers as well as with environmental groups and government regulators. Mr. Jonker has served as an expert witness on technical and policy matters before numerous regulatory and legislative bodies, including the California Public Utilities Commission, the Federal Energy Regulatory Commission (FERC) and a multitude of federal, state, regional and local environmental agencies. He is a skilled leader and energetic "can-do" problem solver, with a track record of achieving innovative, productive changes and rational, pragmatic, win-win solutions.

From 1981 to 2000, Mr. Jonker held various positions of increasing responsibility with the Sempra Energy holding company and two of its predecessor companies, including Southern California Gas Co., the largest natural gas utility in the U.S., retiring as Sempra's Corporate Director of Environment & Safety. An example of his successes is his initiation and implementation of a strategy for site assessment, mitigation and ultimate disposal of contaminated former gas manufacturing facilities that ensures rate recovery of nearly $70 million of at-risk clean-up costs. Prior to that he held a wide variety of positions with Union Oil Company and Tosco Corporation, as both engineer and lawyer, spending three years as a researcher at Union Oil Co.'s research facility, but charged primarily with ensuring company operations achieved and maintained compliance with regulations adopted under new statutes and regulations. While at Tosco he was responsible for obtaining and maintaining all environmental permits for Tosco's refining, marketing, crude oil production and shale oil operations, which included obtaining a federal PSD permit for a grassroots Utah oil shale facility in a record six months.

Mr. Jonker's educational background includes a Juris Doctor, with honors from Western State University (Law Review; Dean's Honor Roll); a M.S. in Chemical Engineering from the University of Southern California (Graduated first in class; Dean's List), and a B.S. in Chemical Engineering, cum laude, University of Southern California (Dean's List; elected to Tau Beta Pi, national engineering honorary).

In wide demand as an advisor, he was appointed by the Clinton Administration to EPA's Clean Air Act Advisory Committee and has been re-appointed by the Bush Administration. California's Governor Wilson appointed Mr. Jonker to the Governor's Permit Reform Advisory Committee, and he has served twice on the South Coast Air Quality Management District Advisory Council, where he chaired the Planning Committee. He is a former Director of the California Council for Environmental and Economic Balance and currently serves as Board member of the Air and Waste Management Association.

James R. Kliegel, Ph.D., Chief Technical Officer
Prior to joining GES, Dr. Kliegel had a career as a scientist, inventor, executive at a large aerospace firm, founder of several businesses and consultant. He joined Space Technology Laboratories (which later became TRW Systems Group) in 1958, where, among other things, he had major design responsibility for performance of Apollo astronaut lunar landing engines. While there he developed nationally adopted rocket engine performance analysis computer programs still in use today, while earning four NASA awards for excellence and obtaining secret USAF clearance.

As President of Dynamic Science, a small combustion research company, he developed the first crash-worthy helicopter fuel systems, causing accident survival rates to jump from 20 to 80%. Products developed by Dynamic Science are still in use today.

Soon thereafter he founded KVB, Inc., where he served as President and Board Chairman. Under Jim's leadership KVB developed into the nationally recognized leader in solving operational and environmental problems associated with power generation equipment, specifically related to control of NOx emissions through advanced combustion technologies. While at KVB Dr. Kliegel served on President-elect Reagan's Environmental Transition Task Force, and also served as Chairman of the National Academy of Sciences panel investigating the technical feasibility of the newly proposed vehicular CO emission standard.

After KVB was sold, Jim rejoined TRW, where, having been granted top secret USAF clearance, he managed and directed a number of advanced research and development efforts for the military, including for the Strategic Defense Initiative and the Minuteman, Peacekeeper and small ICBM missile programs. As a member of TRW's senior technical staff, he contributed to all propulsion programs of TRW's Ballistic Missile Division.

Jim holds a B.S. degree from CalTech in applied chemistry, as well M.S. and Ph.D. degrees from UC Berkeley, in chemical and mechanical engineering respectively.

Roger W. Krueger, Director of Operations
Mr. Krueger has demonstrated leadership in motivating and administrating results-oriented management teams. He is highly organized, self-motivated with strong communication, computer, presentation, and public relation skills. He is proficient in structuring and managing complex budgets, including cost analysis and reporting with hands-on experience in financial and contract management, personnel administration, supervision, scheduling, production operations, facility development, and information systems. His management style is direct and decisive, yet flexible in responding to changing operational, financial and organizational demands.

Mr. Krueger's professional experience with Kelly Space & Technology, Inc. is focused on initiating and managing subcontracting, consulting, and licensing contracts. He manages patent submissions and directed the preparation of successful research and development proposals. He originated KST's configuration management, data retrieval and documentation support systems for a multi-million dollar, commercial space launch development program. Significant accomplishments include:

- *Contracting manager for a $19M, NASA Systems Engineering Program proposal*. As prime contracting representative, ensured compliance with administrative, legal and contractual requirements for submission of the proposal and coordinated proposal documentation and teaming agreements with support subcontractors and consultants.
- *Operations and Contract Manager for a $3.1M NASA Launch Vehicle Risk Reduction Development Program.* Negotiated and managed the prime contract and 13 subcontracts. Provided contractual direction and ensured contract compliance for all subcontractors and consultants.
- *Managed prime contract and six subcontracts for a $1.3M, NASA Space Travel Architecture Study Program*.
- *Proposal and Program Manager for a $180K, California Technology Grant awarded to develop a systems integration laboratory in support of software and hardware development relating to space vehicle attitude control.*
- *Contract Manager for a $230K, California Highway to Space Grant to identify operational and environmental requirements for launching commercial space vehicles from sites in California*.
- *Proposal Manager for an $80K, California State Incubator Grant awarded to encourage start-up companies to locate in economically depressed areas.*

Mr. Krueger is a former Naval Aviator and currently serves as Airport Commissioner for the City of Riverside, California. He received a Bachelors Degree (BA) in Industrial Management and Economics from Purdue University and a Masters Degree (MBA) in Business Administration and Operations Management from Southern New Hampshire University.

Daniel A. Auzenne, Production and Manufacturing Manager
Mr. Auzenne's experience in manufacturing began in the late 70's working several years as a machinist producing oilfield equipment. In 1981, he was promoted to a supervisor's position while employed by Texas Iron Works, in Youngsville, LA, a company that provided Safety and Kelly valves, along with other types of oilfield products to offshore drilling platforms. During the time he was employed as a supervisor he assumed responsibilities for CNC Programming and Production, Conventional Machining, Product Assembly and Testing, Tooling, and Tool Inventory. He initiated Safety Programs for employees in the different shop areas and a Scheduled Maintenance Program for all machinery and equipment. Mr. Auzenne moved to Southern California in July 1986 and began employment with McDonnell Douglas, now The Boeing Co., at the Torrance Manufacturing Facility. In his eight years at the facility he worked in the Tooling Manufacturing Department, spending five of these years as a Section Manager rotating through different departments gaining manufacturing experience in the application and production of tools. His responsibilities and accomplishments included overseeing the fabrication of tools on commercial aircraft programs such as MD80, MD90 and MD11; and F15, T/A45, and C17 military programs. In his remaining six years of employment with McDonnell Douglas/Boeing, he transferred to Huntington Beach working as a Project Manufacturing Engineer on the Delta II, III, and IV Satellite Launch Vehicles. At this facility, he was responsible for fabrication, and building to schedule, fuel and cryogenic tanks for the 2nd stages of these vehicles, along with supplying LOX tanks and 1-piece 4m diameter tank domes to Mitsubishi Heavy Industries for the HII-SLV. Mr. Auzenne currently works with a team of engineers, chemists, and scientist developing a natural gas generator for Global Energy Systems, LLC, a subsidiary of Kelly Space and Technology, Inc.

Robert N. Keltner, Program Manager
Mr. Keltner has over 30 years of hands-on hardware experience: launch range operations & safety, environmental control; electrical power; ordnance devices; physical security; and facility construction. Extensive experience in: system engineering; conceptual and detail design; structural analysis; life cycle costing; preparation of plans, procedures, manufacturing; and development, and flight and systems testing. As KST Project Manager, he directed activities of KST personnel and subcontractors in a cooperative effort with the Air Force Research Laboratory, NASA Dryden Flight Research Center and Air Force Flight Test Center to perform design, analysis and test for our highly successful Tow Launch Demonstration Program. Upon conclusion of this program, he prepared a very detailed program description report that brought KST the prestigious annual Tibbetts award, which is the Small Business Administration's annual recognition of "models of technical excellence". One of Mr. Keltner's current duties is to serve as the Executive Secretary of the Federal Aviation Administration (FAA) Commercial Space Transportation Advisory Committee (COMSTAC) RLV Working Group, of which Mike Kelly is current Chairman. As a past TRW Program Manager and Senior Project Engineer, he directed Architectural, Engineering and Aerospace contractors on the Peacekeeper ICBM Program. As a Project Manager for Daniel, Mann, Johnson and Mendenhall (DMJM), he directed the test planning and procedures for the Apollo Lunar Excursion Module. At General Dynamics Astronautics as Launch Site Manager and Design Group Manager, he directed the installation, checkout and launch, and mechanical, electrical and facilities remedial design activities on the Atlas missile system.

Vehicle: (unnamed)
Developer: Armadillo Aerospace
Launch Price: $200,000
No. Passengers: 2
Payload to 100km: 440 lbs
Contact Info: John Carmack
johnc@idsoftware.com

General Description

The Armadillo Aerospace concept is a single-stage, piloted, vertical-takeoff and vertical-landing vehicle. Armadillo Aerospace is currently developing hardware and is designing the RLV configuration and operational modes in a “design-as-we-build” approach. The first vehicle built by Armadillo Aerospace will be a single-crew RLV which will travel to an altitude just under 62 miles (100km). The follow-on vehicle will be X-Prize class, able to carry 2 passengers. The first vehicles will use a hydrogen peroxide monopropellant engine being developed by Armadillo Aerospace, while the follow-on X-Prize class vehicle will most likely use a peroxide/kerosene engine.

Concept of Operations

The Armadillo Aerospace concept takes off vertically. A single hydrogen peroxide engine, as well as rocket-powered rotor blades, will power the initial phase of the ascent. Four canted attitude control engines will provide 3-axis stabilization. The Armadillo Aerospace vehicle will achieve a peak altitude of 62 miles (100 km). Rocket-powered rotor-blades will be used to guide the vehicle on descent and provide a soft landing.

Cost and Schedule

Development Cost	$1 M (self-funded by multi-millionaire John Carmack)
Development Schedule	2 yrs

Performance

Payload Capability	440 lbs/2 passengers
Price per Flight	$100,000

Logistics

Turnaround Time	Less than 1 week
Potential Launch Sites	Oklahoma Spaceport

Configuration-Airframe

No. Crew	1
Length	Undetermined
Diameter (Width)	Undetermined
Gross Weight	7,000 lbs
Propellant Weight	5,500 lbs
Propellant Type	Kerosene/Hydrogen Peroxide

Configuration-Engine

Engine	Kerosene/Peroxide engine developed by Armadillo Aerospace
Number of Engines	1
Sea Level Thrust	10,000 lbs

Growth Options

Armadillo Aerospace's concept can be used as a booster for an additional upper stage that would be capable of placing nanosat class payloads in LEO.

Vehicle: StarBooster 4
Developer: Starcraft Boosters, Inc.
Launch Price: $750,000
No. Passengers: 0
Payload to 100km: 3,800 lbs
Contact Info: Hu Davis
(830) 935-2743

General Description

The StarBooster is a family of reusable booster systems that integrates with current launch systems (e.g., StarBooster 4 with the Black Brant sounding rocket, StarBooster 750 used as a flyback booster for the Space Shuttle). The StarBooster system consists of a patented reusable airframe "shell" and removable propulsion module, which is designed for separate servicing after flight. The StarBooster has various sizes, with specific designations such as StarBooster 4, StarBooster 30, StarBooster 200, where the numbers refer to the short tons of propellant used.

Concept of Operations

The StarBooster 4 launches vertically from a coastal launch site, and provides the total impulse required to place an upper stage(s) at Mach 3.0 and 80,000 ft. After performing an aerodynamic separation maneuver, StarBooster 4 pitches to a high angle-of-attack to decelerate to low enough speeds to perform a subsonic turn-around maneuver and glide back to a runway landing at the launch site.

Cost and Schedule

Development Cost	$115M (includes nanosat class orbital system)
Development Schedule	In progress, 2006 projected operational capability

Performance

Payload Capability to 100km	3,800 lbs
Price per Flight	$750,000

Logistics

Turnaround Time	48-72 hours
Potential Launch Sites	Wallops, Virginia Spaceport, or any coastal launch site

Configuration-Airframe

No. Crew	0
Length	34 ft
Diameter (Width)	3.7 ft
Wingspan	17 ft
Gross Weight	16,300 lb
Propellant Weight	8,800
Propellant Type	Kerosene/LOX

Configuration-Engine

Engine	AFRL Pressure-Fed Engines
Number of Engines	2
Sea Level Thrust	17,300 lbs

Growth Options

Starcraft Boosters, Inc. is planning a modular approach to larger growth options. The StarBooster can be combined with another StarBooster, expendable and reusable stages, and optional drop tanks (based on the reusable propulsion module) to provide various lift capabilities to orbit, including small payloads, heavy payloads, and orbital space tourism.

STARCRAFT BOOSTERS, INC. MANAGEMENT BIOS

Dr. Buzz Aldrin, Chairman of the Board of Directors
Dr. Aldrin is best known for his work as an Apollo astronaut who made the first Moon landing. Dr. Aldrin is an honors graduate of West Point and earned his Ph.D. in aerospace engineering from MIT. His work was the basis for the rendezvous and docking techniques used by the Apollo missions. Dr. Aldrin served as Commander of the USAF Test Pilots' School at Edwards AFB. He co-invented StarBooster and has been tireless in promoting its technical and cost benefits. Dr. Aldrin has a unique ability to meet with anyone from Presidents to CEOs. Dr. Aldrin has a personal relationship with members of Congress and other highly placed people.

Lt. General Dirk Jameson (USAF retired), President and CEO
Lt. General Dirk Jameson commanded the 14,500 men and women of the U.S. Twentieth Air Force. In this position, Lt. Gen. Jameson was responsible for all U.S. Intercontinental Ballistic Missiles, seven major subordinate units, operational training, testing, security and readiness. Lt. Gen. Jameson also served as Deputy Commander in Chief U.S. Strategic Command. In this position he was responsible for management of a headquarters staff of 4,000 men and women. Lt. Gen. Jameson also commanded the USAF Strategic Missile Center at Vandenberg AFB, California. In this position he ran the Air Force's third largest base staffed with ten thousand military, civilian and contractor employees. He managed a 100,000-acre military test base with over ten billion dollars infrastructure investment and an operating budget of $100 million per year. Lt. Gen. Jameson has served as President of Arrowsmith Technologies, Inc., a software development company and served as Vice President of Alliant Techsystems, Inc., a large defense contractor.

Hubert P. Davis, Vice-President of Engineering and Development
Mr. Davis has for decades been a leading launch vehicle designer in the U.S. During his 17 years at NASA, Mr. Davis was responsible for three successful Apollo lunar landing vehicles (Lunar Modules) and was the manager of future programs at the NASA Johnson Space Center in Houston. After retiring from NASA, Mr. Davis founded and was CEO of Eagle Engineering, a multimillion-dollar per year private aerospace engineering consulting firm. Mr. Davis has spent the last five years doing the engineering studies SBI has needed to convert the StarBooster concept into a solidly designed and marketable space launch vehicle system. Mr. Davis will lead the engineering team that will reduce the StarBooster technology to practice.

Arthur M. Dula, Vice-President, Legal
Mr. Dula is a leading U.S. aerospace corporate and patent attorney. Mr. Dula is the past Chairman of the American Bar Association Section of Science and Technology and headed its Aerospace Law Division. He was a legal advisor to NASA on the Space Shuttle Contract and advised the U.S. Congress on the legal regime for the International Space Station. Mr. Dula served as corporate and patent lawyer for SpaceHab, Inc. from its formation, through $120 million of international venture funding, to its public offering. SpaceHab is now a successful public company. Mr. Dula was also the legal

advisor to the first private space launch and helped draft the U.S. law that controls the licensing of private space launch services. Mr. Dula has served as Professor of Aerospace Law at the University of Houston, as a Professor of Law at the Institute of State and Law in Moscow, and as the Brennen Distinguished Professor of Law at the University of Akron.

Dr. Ted Talay , Director of Systems Analysis

Dr. Talay, retired from NASA's Langley Research Center after thirty years of service. Dr. Talay is a recognized expert in aerospace system design and has specialized in launch system design and analysis. At NASA, Dr. Talay worked partially and fully reusable launch vehicle systems including two-stage and crew transfer vehicle systems. Dr. Talay led and managed numerous studies of next generation transportation systems at NASA and served as Branch Chief of the Vehicle Analysis Branch. His recent work before his retirement included small booster design for cost-effective small satellite and rapid response missions. Education includes a B.S. and M.S. in Aeronautical Engineering and Astronautics, and a Ph.D. in Engineering.

Vehicle: Michelle-B
Developer: TGV Rockets
Launch Price: $1 M
No. Passengers: 0-5
Payload to 100km: 2,200 lbs
Contact Info: Pat Bahn
(301) 913-0071

General Description

Michelle-B is a single-stage, piloted, vertical-takeoff and vertical-landing vehicle. The vehicle is fully transportable, so it can operate out of most launch sites, land or sea. The configuration of the Michelle-B conforms to industrial standards to facilitate handling and transport by sea, land, and air using common, commercial equipment. Six pressure-fed engines power the Michelle-B, enabling it to reach altitudes of 62 miles (100 km).

Concept of Operations

The Michelle-B takes off vertically, and the powered ascent lasts for approximately 80 seconds using varied power settings to manage dynamic pressure loads. The Michelle-B cruises to a maximum altitude of 62 miles (100 km), and spends 200 seconds in micro-gravity. This is followed by a gravity-induced descent. A flexible aerodynamic decelerator is deployed to reduce speed and moderate re-entry temperatures. At an altitude of approximately 1 mile, the shield begins to retract, and the pilot re-starts the engines to further slow the vehicle. The Michelle-B lands vertically on its stowable landing legs. The pilot manages terminal maneuvers and all systems.

Cost and Schedule

Development Cost	$50M (includes production of 3 vehicles)
Development Schedule	2 years

Performance

Payload Capability	2,200 lb
Price per Flight	$1 Million

Logistics

Turnaround Time	A few hours
Potential Launch Sites	Oklahoma, Wallops Island as initial sites

Configuration-Airframe

No. Crew	1
Length	37.4 ft
Diameter (Width)	7.9 ft
Gross Weight	61,327 lb
Propellant Weight	43,692 lb
Propellant Type	Kerosene/LOX or Alcohol/LOX

Configuration-Engine

Engine	Aero-Astro PA-X-30K
Number of Engines	6
Sea Level Thrust	30,000 lb

Growth Options

TGV is targeting the suborbital market, but as the systems mature, the modular nature of the Michelle-B will allow growth into higher performance markets. Further, the use of an expendable upper stage will allow the Michelle-B to serve missile defense target missions or micro-satellite launches.

TGV-ROCKETS MANAGEMENT BIOS

Pat Bahn, Chief Executive Officer
Mr. Bahn has worked most of his career in the computer industry. Starting in 1970 in data entry, he worked in operations and support eventually moving into programming. Mr. Bahn was involved in communications systems development, including Internet development. Mr. Bahn has worked in small business and consulting since 1970. Mr. Bahn received a BS in Engineering Management from Clarkson College in 1984 and a MBA/MPA from Southeastern University in 1991.

Earl Renaud, Ph.D., Chief Operating Officer
Dr. Renaud has worked in aerospace for more than 10 years for Boeing, United Technologies Pratt & Whitney and Aurora Flight Sciences. He was the head of the Systems Engineering and Analysis Group at Aurora, responsible for the conceptual design of high altitude aircraft and aircraft-systems. Prior to Aurora he worked as an applications engineer in the field of massively parallel supercomputers for Thinking Machines Corporation. For the past several years Dr. Renaud has been an independent consultant providing consulting services to government and private sector customers in the fields of aerospace systems and information technology. Dr. Renaud received his BS from the University of Michigan and his Ph.D. from the Massachusetts Institute of Technology in 1991, with a major in Aeronautics and Astronautics and a minor in Management of Technology from the Sloan School of Management.

Kent W. Ewing, Chairman
A former career Naval officer, Kent comes to TGV from Leitch Incorporated, which he joined in 1993 as Director of Government Programs. He served as President from February 1996 to May 1998. Before starting at Leitch, Kent was Commanding Officer of the USS America (CV-66) during Desert Storm. In his Naval Career he also commanded USS Sylvania (AFS-2), Carrier Air Wing Seventeen, and Attack Squadron Sixty Six. He has flown 7500 hours in over 100 different military and commercial aircraft, and made over 1150 carrier landings. Kent holds a Bachelor of Science degree in Economics from the University of California at Los Angeles and a Masters of Science in Systems Management from the University of Southern California. A Dayton, Ohio native, Kent also is a 1974 graduate of the U.S. Navy Test Pilot School, Patuxent River, Class 65. In 1986 he was selected as a Senior Executive Fellow to the Harvard JFK School of Government. He has been a member of the Society of Experimental Test Pilots since 1976 and a member of the Society of Motion Picture and Television Engineers since 1993.

Len Cormier, Chief Engineer
Mr. Cormier has dedicated most of his efforts during the past 40 years to the pursuit of lower cost access to space. He began his career in the space business at the National Academy of Sciences in 1956 and at NASA headquarters in 1959. In the early and mid-1960s he was project engineer for space transportation systems at the Los Angeles Division of North American Aviation, Inc. After that he worked as a project engineer and program manager for Fighter Systems at North American-Rockwell. Mr. Cormier

formed his own company in 1967 to pursue commercial space launch consulting, which he has continued for the past thirty years with a wide variety of aerospace consulting projects. From 1943 to 1967, Mr. Cormier served as a Naval Aviation cadet, Navy fighter pilot, and executive officer of an ASW patrol squadron on active duty and in the Naval Reserve. Len holds a BA in physics from the University of California. Len speaks Russian and is proficient in Pascal. Len was a charter member and a re-appointed member of the Dept. of Transportation's Commercial Space Transportation Advisory Committee (COMSTAC). Presently, Mr. Cormier is president of PanAero, Inc. and Third Millenium Aerospace, Inc. PanAero, Inc. is participating in the X-Prize and has recently been awarded a contract by DARPA for the RASCAL concept, with Coleman as a prime contractor.

APPENDIX A.2

DOMESTIC SUBORBITAL RLVs UNDER STUDY

Vehicle:	SLC-S1	
Developer:	Space Launch Corporation	
Launch Price:	$1.2 M	
No. Passengers:	0	
Payload to 100km:	3,800 lbs	
Contact Info:	Jacob Lopata (714) 432-6410	

General Description

The SLC-S1 consists of single stage solid expendable vehicle that is air-launched from the bottom of a jet aircraft. The SLC-S1 is a single stage derivative of the company's three-stage orbital system, the SLC-1, which is currently under development (and has reached the preliminary design phase). The SLC-S1 will be able to deliver 1,000 lb to greater than 287 miles providing more than 10 minutes of micro gravity time. Only existing technology will be utilized.

Concept of Operations

The concept of operations for the SLC-S1 is similar to current operational practices for tactical air-to-air and air-to-ground missiles. The expendable rocket will be integrated with the aircraft using ground support equipment similar to that used for tactical missiles. At a given altitude, the single stage expendable launch vehicle will be released from the underbelly of the jet aircraft, and its solid rocket motor ignited. The expendable launch vehicle will not be recovered, but the jet aircraft will return to the launch site.

Cost and Schedule

Development Cost	Under Study ($22M for orbital vehicle)
Development Schedule	2 yrs

Performance

Payload Capability to 100 km	3,800 lbs
Price per Flight	$1.2 M

Logistics

Turnaround Time	Less than 24 hrs
Potential Launch Sites	Any conventional runway

Assist Aircraft

Aircraft	F-4 Phantom
Type of Assist	Underbelly carriage
No. Crew	1
Aircraft Gross Weight	56,000 lbs
Aircraft Empty Weigh	32,000 lbs
Aircraft Length	58.2 ft
Aircraft Wingspan	38.5 ft
Engines	General Electric J-79-GE-15 engines with afterburners
Number of Engines	2

ELV Configuration-Airframe

No. Crew	0
Length	Under Study
Diameter (Width)	2.5 ft
Gross Weight	Under Study
Propellant Weight	2,800 lbs
Propellant Type	HTPB/AP/Al

ELV Configuration-Engine

Engine	Solid Rocket Motor
Number of Engines	1
Sea Level Thrust	18,500

Growth Options

The SLC-S1 is a single stage derivative of the SLC-1, which is in development. The SLC-1 will be capable of delivering 130 lbs to Low Earth Orbit.

SPACE LAUNCH CORPORATION MANAGEMENT BIOS

Jacob Lopata, Chief Executive Officer

Prior to co-founding the Space Launch Corporation, Mr. Lopata worked at Rotary Rocket Company, a high technology start-up looking to develop a fully reusable launch vehicle called the Roton. At Rotary Rocket, he was responsible for the thermo-mechanical analysis of the regenerative cooling circuit for the Roton main propulsion system. He was instrumental in preparing the engine for fabrication, overseeing integration of subsystems and assisting with its overall design. In addition to his work with Rotary Rocket, Mr. Lopata has co-authored several studies on the conceptual design of a dedicated launch vehicle for small payloads. He has conducted research for NASA at the Goddard Space Flight Center and attended NASA Academy, a selective leadership-training program. Mr. Lopata earned his M.S. in Aeronautics & Astronautics from MIT studying rocket propulsion, systems engineering, spacecraft design, and at the MIT Sloan School of Management, technology entrepreneurship. He earned his B.S. in Aerospace Engineering, graduating with high honors, from the Illinois Institute of Technology in Chicago. Prior to that, Mr. Lopata earned a B.A. from the University of Illinois in Urbana where he studied political science and became a commercial pilot and flight instructor.

Michele Cook, President

Prior to joining the Space Launch team, Ms. Cook co-founded Technanogy Air & Space and served as the company's president and COO. In that role, Ms. Cook successfully lead the business development efforts for both government and commercial customers, managing an aggressive proposal process that produced an enviable 100% DoD win rate (7 of 7 successful bids) in the first six months of the company's existence, building a respectable pipeline and a strong business infrastructure to then support the execution of the contracts. Ms. Cook has over 15 years experience in coordinating and managing engineering and scientific research groups, most recently in projects sponsored by the Defense Advanced Research Projects Agency (DARPA), the Office of the Secretary of Defense (OSD), and the DARPA/DISA Advanced Information Services Joint Program Office (AITS JPO). The majority of these programs involved multi-disciplinary research activities focused on advanced technology for the nation's defense. Ms. Cook also has many years experience in the private sector in all aspects of business administration.

George Whittinghill, Chief Technical Officer

Mr. Whittinghill, a successful entrepreneur and a recognized industry leader in hybrid rocket propulsion systems, comes to The Space Launch Corporation from Technanogy Air & Space (TAS). As the CEO and Chief Technical Officer for TAS, Mr. Whittinghill provided senior technical and business oversight to all of the company's propulsion research efforts with a current customer roster to include all three military Services, the state of California and two programs with the National Reconnaissance Office. Mr. Whittinghill has been the program manager and technical lead for NASA and Air Force propulsion hardware projects, commercial space projects and Department of Defense (DoD) robotic projects. Formerly Director of Special Projects at American Rocket Company (AMROC), Mr. Whittinghill was responsible for hardware development of hybrid propulsion systems, advanced motor and launch vehicle concepts. Mr.

Whittinghill also worked at NASA's Johnson Space Center in the Mission Operations Directorate and is experienced in both manned and unmanned spacecraft operations. Mr. Whittinghill brings more than 23 years of experience in developing and managing advanced technology programs with Northrop, McDonnell Douglas, NASA/JSC, Space Industries, American Rocket Company and ISX Corp. Mr. Whittinghill has a B.S. and an M.S. in Aeronautics and Astronautics from MIT.

Michel Kamel, Ph.D., Director, Chief Operations Officer
Before co-founding The Space Launch Corporation, Dr. Kamel worked for the Rotary Rocket Company where he managed the production and testing of two generations of auxiliary hydrogen-peroxide thrusters, including those that powered the Roton Atmospheric Test Vehicle through its ground and flight tests. While at Rotary, Dr. Kamel also performed engine analysis, straight and dual nozzle optimization, heat transfer calculations, transpiration and injection cooling analysis. He also produced a study on aerospike engines as well as performed trajectory optimization calculations. Dr. Kamel received his Ph.D. from the mechanical engineering department of Stanford University. There he designed and built a 30 ft. facility to investigate hypersonic combustion phenomena. As part of his research work at Stanford, Dr. Kamel published and presented his results at more than a dozen national and international conferences and workshops. Dr. Kamel's stay at Stanford was also marked by his pursuit of courses in decision analysis and strategic planning, which culminated in an internship as a strategy consultant with a Silicon Valley company. Dr. Kamel received his B.Eng. and M.Eng. degrees from McGill University, Canada, where he specialized in the study of gaseous detonation. Dr. Kamel has also been involved in the founding of several student and non-profit organizations, and has served on church councils.

Christopher Smith, Senior Propulsion Engineer
Mr. Smith comes to the Space Launch Corporation from Technanogy LLC, where he was the lead scientist in the R&D of nanotechnology-based solid propellant. Prior to Technanogy, Mr. Smith worked at Pratt & Whitney's Chemical Systems Division, San Jose, CA. There he acted as a senior engineer responsible for the design and test of ordnance and rocket nozzle systems for use on projects such as National Missile Defense and Theater High Altitude Area Defense. Further propulsion experience comes from his time at Rotary Rocket Company. At Rotary he was responsible for a rotating, dynamic rocket motor test stand, which could supply a g field capable of producing loads in excess of 120,000 pounds. He also produced solid propellant ignition systems for the company's proprietary combustors. Mr. Smith has also made progress through his independent work to design, manufacture and test more than one hundred different propellant formulae and rocket motors.

APPENDIX A.3

INTERNATIONAL SUBORBITAL RLVs IN DEVELOPMENT

Country:	United Kingdom
Vehicle:	Ascender
Developer:	Bristol Spaceplanes Ltd.
Launch Price:	$200,000
No. Passengers:	2
Payload to 100km:	440 lbs
Contact Info:	David Ashford 44 1454 613 907

General Description

The Ascender operates similar to an aircraft, taking off and landing horizontally with existing jet engines, and operating out of, and integrating with, conventional airports and the current air traffic control system. The aerodynamics, structure, engines and systems are all based on those of existing airplanes or launchers. The Ascender is powered by two jet engines and one rocket engine, enabling it to reach altitudes of 62 miles (100 km).

Concept of Operations

The Ascender takes off from a conventional airport with its two jet engines, and climbs to a height of 26,000 ft. The rocket engine is then ignited, and accelerates the vehicle in a steep climb to a speed of Mach 2.8. The Ascender then coasts to a maximum height of 62 miles (100 km). The vehicle returns to the airport under the power of its jet engines.

Cost and Schedule

Development Cost	$50M- $100M for an operational prototype, another $200M- $300 M for a fully certificated vehicle
Development Schedule	3 years for operational prototype, plus 3-4 more years for a fully certificated vehicle

Performance

Payload Capability	2 passengers/ 440 lbs
Price per Flight	$200,000 ($100,000 per passenger)

Logistics

Turnaround Time	1 week (a few hours once the vehicle is mature)
Potential Launch Sites	Any conventional runway

Configuration-Airframe

No. Crew	2
Length	44.9 ft
Wingspan	25.9 ft
Gross Weight	9,900 lbs
Propellant Weight	5,000 lbs
Rocket Propellant Type	Hydrogen/LOX

Configuration-Engine

	Jet Engine	**Rocket Engine**
Type of Propulsion	Turbofan	Rocket
Engine	Williams-Rolls FJ44	Pratt & Whitney RL-10
Number of Engines	2	1
Sea Level Thrust	2,300 lbs per engine	14,000 lbs

Growth Options

Ascender would lead to a fully orbital spaceplane called Spacecab. Development of the Spacecab would lead to the larger Spacebus, which would carry 50 people to orbit.

BRISTOL SPACEPLANES LTD MANAGEMENT BIOS

David Ashford, Managing Director

Mr. Ashford obtained a BSc in Aeronautical Engineering, class 2.1, from Imperial College in 1960. He then spent a year at Princeton University as a post-graduate research assistant on rocket motor combustion instability. He then joined the Hawker Siddeley Aviation Advanced Projects Group as an aerodynamicist and pre-design engineer on spaceplane and advanced aeroplane projects. This was followed by two and a half years at Douglas Aircraft, Long Beach, as an aerodynamicist on the DC-8, project engineer on the DC-10, and pre-design engineer on new projects. He then joined BAC/BAe in the Concorde Pre-Design Group as a project engineer co-coordinating studies of stretched versions of Concorde, and other new projects. This was followed by four years in the Skylark Sounding Rocket Project Office as sales engineer and project manager for exports and new projects. He then joined the Naval Weapons Division as project manager of various guided weapon and EW development projects, managing development teams of up to 40 engineers. He then joined the Rutherford Appleton Laboratory as a consulting project manager of a multi-national earth observation satellite instrument project. He founded Bristol Spaceplanes Limited in 1991. Mr. Ashford is a former private pilot and gliding instructor, and has had published more than twenty papers on aerospace subjects in the professional and technical press. He co-wrote "Your Spaceflight Manual", the first serious book on space tourism.

David Kent, Chief Designer

Mr. Kent obtained his BSc Pt 1 (London University), Aeronautical Engineering, Loughborough College in 1956. His experience includes: stressman, designer and project engineer with Armstrong Whitworth Aircraft, Edgar Percival Aircraft, Thurston Engineering Ltd, Aviation Traders Ltd, F G Miles Aircraft Ltd, Servotec Ltd, Lockheed Georgia (C-5A wing design), and Slingsby Sailplanes Ltd. He then joined Hawker Siddeley Aviation doing research into VTO aircraft, including development of test equipment and test models. As assistant editor for "Flight International" magazine, responsible for the Private Flying section, Mr. Kent flew some 25 types of aircraft for flight reports. He then led the team doing the detail design and construction of the *Leopard* four-seat twin jet, followed by designing and building major structural components, and carrying out test flights, on the *Optica*. He then carried out design improvements, stressing, construction, flight testing, and jigging design for the *Petrel* two seat light aeroplane, followed by the design and construction of the *Duet* glass fibre microlight prototype, sixteen copies of which were built by a subcontractor. This was followed by the structural design of Canard *Jet Cruzer* prototype, which was built in the USA.

Country:	Canada
Vehicle:	Canadian Arrow
Developer:	Canadian Arrow
Launch Price:	Proprietary
No. Passengers:	1-2
Payload to 100km:	220-440 lbs
Contact Info:	Jeff Sheerin (519) 668-0607

General Description

The Canadian Arrow is a two-stage, piloted, vertical takeoff and vertical landing vehicle. It is modeled after the V-2 ballistic rocket developed by Werner Von Braun and the German army in WWII, which had a gross weight of 24,000 lbs, a range of 200 miles, and a payload capability of 2,000 lbs. A 57,000 lb thrust pressure-fed first-stage engine, and 4 second-stage JATO-type rocket engines will propel the Canadian Arrow to an altitude of 70 miles (112 km).

Concept of Operations

The Canadian Arrow takes off vertically, and the first stage burns for approximately 55 seconds, carrying the vehicle to an altitude of 90,000 ft. During ascent, graphite vanes in the exhaust gas ensure a stable flight until enough speed has been built up to allow the aerodynamic fins to function. At approximately 264,000 ft (50 miles), the second stage ignites its engines and propels the vehicle to a peak altitude of 70 miles. The first stage has meanwhile descended, using 4 parachutes to slow its descent speed to 30 ft/sec for a gentle splashdown in the water approximately 10 miles down range. The first stage has positive buoyancy without flotation gear. A recovery ship will lift the booster from the water and carry it back to base for processing and re-launch. The second stage, on descent, deploys a ram air ballute to slow itself to subsonic speeds. Next, three main parachutes are deployed, slowing the vehicle to a gentle splashdown approximately 15 miles down range. The crew cabin has a low center of gravity so that when floating on the water, the cabin will roll over to a stable position with the hatches facing up. After reorienting itself, inflatable floats are deployed on each side of the cabin to make the whole craft a very stable raft on the water. The crew can now open the hatches and stand up if they want to, while waiting for the recovery vessel.

Cost and Schedule

Development Cost	Proprietary, includes 2 vehicles
Development Schedule	1.5 yrs

Performance

Payload Capability	1-2 passengers/220-440 lbs
Price per Flight	Proprietary

Logistics

Turnaround Time	1-2 weeks
Potential Launch Sites	Churchill, Manitoba on Hudson Bay, possible Wallops, could be any coastal location

Configuration-Airframe

	Stage 1	Stage 2
No. Crew	0	1-2
Length	33.5 ft	20 ft
Diameter (Width)	5.4 ft	5.4 ft
Gross Weight	32,000 lb	Proprietary
Propellant Weight	Proprietary	Proprietary
Propellant Type	Alcohol/LOX	Solid Propellant

Configuration-Engine

	Stage 1	Stage 2
Engine	Reproduction of the V-2 rocket engine thrust chamber, pressure-fed	JATO-type
Number of Engines	1	4
Sea Level Thrust	57,000 lb	Proprietary

Growth Options

None, Canadian Arrow is only targeting the suborbital space tourism market.

Country:	Russia	
Vehicle:	Cosmopolis XXI	
Developer:	Myasishchev Design Bureau	
Launch Price:	$200,000	
No. Passengers:	2	
Payload to 100km:	440 lbs	
Contact Info:	Tereza Predescu (703) 524-7172	

General Description

The Cosmopolis XXI launch system consists of a carrier aircraft, the Russian M-55X, and a manned rocket module, the C-21. The C-21 is a Russian built vehicle that leverages technology developed for the Buran ("the Russian Space Shuttle"). The Cosmpolis XXI is intended for operations out of Russia, using conventional airports and launch sites. A single solid-propellant Russian engine, the [insert here], propels the C-21 module to an altitude of 62 miles (100km).

Concept of Operations

The Cosmopolis XXI takes off horizontally from a conventional airport or launch site. The C-21 module piggybacks on the single-pilot M-55X carrier aircraft. The M-55X carries the C-21 module to an altitude of 20 kilometers and a trajectory angle of 40-60 degrees to the horizon. At this point, the C-21 is disengaged from the M-55X, and as soon as a safe separation distance is achieved, the C-21's rocket engine is ignited. The C-21 then climbs steadily under rocket power, on a gradual trajectory, to an altitude of 62 miles (100 km). Once the rocket engine burns out, the engine compartment separates from the crew capsule. The C-21 then continues to gain altitude as it passes through suborbital space. During the descent phase back to Earth, control surfaces are extended for optimal aerodynamic performance. The landing is divided into the lifting body glide-phase and the final parachute-assisted touch down.

Cost and Schedule

Development Cost	$12 M
Development Schedule	2.5 yrs

Performance

Payload Capability	2 passengers
Price per Flight	$200,000 ($100,000 per passenger)

Logistics

Turnaround Time	Less than 2 weeks
Potential Launch Sites	Any conventional runway

Assist Aircraft

Aircraft	M-55 Geophysica
Type of Assist	Piggyback
No. Crew	1
Aircraft Gross Weight	55,000 lbs
Aircraft Empty Weigh	31,000 lbs
Aircraft Length	75 ft
Aircraft Wingspan	123 ft
Engines	PS-30V12
Number of Engines	2

RLV Configuration-Airframe

No. Crew	1
Length	26.25 ft
Wingspan	17.72 ft
Gross Weight	6,000 lbs
Propellant Weight	information not available
Propellant Type	information not available

RLV Configuration-Engine

Engine	solid rocket motor
Number of Engines	1
Sea Level Thrust	6,300 lbs

Growth Options

The Myasishchev Design Bureau has experience developing orbital launch systems, such as the Buran, and can leverage this experience, as well as the experience garnered from operating the Cosmopolis XXI, to develop a system for serving orbital launch markets.

Country: United Kingdom
Vehicle: Thunderbird
Developer: Starchaser Industries
Launch Price: $100K - $250K
No. Passengers: 2
Payload to 100km: 440 lbs
Contact Info: Steven Bennett
+44 161-882-9922

General Description

Thunderbird is a two-stage, piloted, vertical-takeoff and vertical-landing vehicle. Each stage of the Thunderbird will use a hybrid engine developed by Starchaser Industries to carry 2 passengers to an altitude of 62 miles (100km).

Concept of Operations

Thunderbird begins its ascent in a vertical orientation under the power of a single 15-ton hybrid rocket engine, as well as four strap-on hybrid rocket motors. Aerodynamic surfaces and a cold gas reaction control system will fine tune the attitude and orientation of the craft. Following main engine cut-off the vehicle will continue to coast on up to an apogee exceeding 62 miles (100 km) where the passengers will experience several minutes of weightlessness. During the ascent phase the command module will separate from the booster and both will re-enter the Earth's atmosphere independently. The recovery systems of both units include parachutes and inflatable airbags.

Cost and Schedule

Development Cost	$5 million ($2.5 million raised thus far)
Development Schedule	2 years

Performance

Payload Capability	2 passengers
Price per Flight	$100,000 - $250,000

Logistics

Turnaround Time	Less than 2 weeks
Potential Launch Sites	Woomera, Australia and possible Canadian launch sites

Configuration-Airframe

	Stage 1	**Stage 2**
No. Crew	0	1
Length	33.5 feet	49.5 feet (inc. capsule)
Diameter (Width)	5.2 feet (not inc. strap-ons)	Max 5.2 feet at capsule
Gross Weight	31,080 lb	13,187 lb
Propellant Weight	17,536 lb	4,783 lb
Propellant Type	HTPB/LOX	HTPB/LOX

Configuration-Engine

	Stage 1	**Stage 2**
Engine	Proprietary Hybrid	Proprietary Hybrid
Number of Engines	1 (plus 4 strap-ons)	1
Sea Level Thrust	33,000 lb per engine	33,000 lb per engine

Growth Options

An orbital vehicle capable of placing 110 lbs in LEO, based on the Thunderbird configuration, is planned.

U.S. DEPARTMENT *of* COMMERCE
OFFICE *of* SPACE COMMERCIALIZATION
Herbert C. Hoover Bldg.
14th Street and Constitution Ave., N.W.
Washington, D.C. 20230

Phone:
(202) 482-6125
(202) 482-5913