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IS THE U.S. LAUNCH PROGRAM REALLY READY FOR THE 21ST CENTURY?

by

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Preface

My interest in space dates back to childhood when I avidly read the works of novelists such as Robert A. Heinlein, C.S. Lewis and Isaac Asimov. Their visions of the future were an endless source of wonder and planted seeds of imagination that flourish to this day. This paper stems from that interest and focuses on a critical area of the 21st century space industry—launch platforms, the means of reaching the next frontier. Still far removed from the easy access envisioned by Heinlein, Lewis, and Asimov, launch systems form the basis for all other space exploration. Without that first critical step into the heavens, mankind would forever be limited to the boundaries of Earth.

Written by a "space novice," this paper is geared towards a similar audience. The intent is to provide an assessment of the space launch industry as it exists today, with an eye towards innovations for tomorrow.

I'd like to acknowledge the support of several individuals in this endeavor beginning with my advisor, Lt Col Mikael Beno. I appreciate his graciousness in accepting me as a research student and thus enduring the task of reading yet another research project. I'd also like to acknowledge the support of my husband, Jay, and my daughters, McKenna and Riley. Their collective sacrifice in family time was crucial to my ability to complete this project. My sincerest "thank you" for understanding.

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Abstract

Following the worst string of space launch failures in the history of the United States space program, (between 1998 and 1999), military and industry analysts are taking a close look at the root causes of the failures and subsequent implications for the industry as a whole. Their findings could significantly impact industry operations and future developmental concepts as the nation heads into the 21st century. Through analysis of existing literature, this paper seeks to review the launch failures and subsequent investigative findings and address what influence, if any, they will have on developmental operations as space launch technologies evolve from expendable launch vehicles to reusable launch vehicles.

Part 1

Introduction

> *If the baby human being shows the same motivation as a young cat, to explore with all his sensors the strange environment he was born into, the big difference is that the little baby soon stands erect. That radical change came in evolution the day described so well by Ovid, a few years after Christ was born. "God elevated the foreheads of man," wrote Ovid, "and ordered him to contemplate the stars."*
>
> — Jacques Cousteau

Since 1958, U.S. launch vehicles have propelled over 777 payloads into orbit for national, civil, and commercial purposes. Yet, despite 40 plus years of experience, "launch still represents the highest risk phase in the life-cycle of satellites."[1] As the United States enters the 21st century, the nation's launch capability has come under question following a disastrous series of launch failures over the course of 10 months between 1998 and 1999. Investigations revealed losses from the three national security and three commercial payloads involved in the accidents totaled more then $3.5 billion. A review of the entire global launch industry for the past decade revealed no more than four failures a year, leaving the United States launch industry with the unenviable distinction of having the worst track record of any country with a total of 14 failures over the past 10 years.[2] This state of affairs leaves U.S. government and industry officials, not to mention customers, questioning whether the U.S. launch program is in fact ready for the 21st century. The primary purpose of this paper is to review the 1998 and 1999 launch failures and subsequent investigative findings to determine what the industry can do to enhance the reliability of future launch programs.

Reliability is a key interest item for government and commercial customers who must currently depend on expendable launch vehicles (ELVs) for the bulk of their space lift requirements. As the launch industry moves into the 21st century, companies are focusing technological developments on future launch capabilities in the form of reusable launch vehicles (RLVs) and evolved expendable launch vehicles (EELVs), deemed to be the most effective paths toward gaining increased reliability and affordability. The goal is to move away from the 1940s and 1950s era technology that laid the foundation for ELV development, which evolved during the 1950s "space race," wherein the primary objective was to develop an organic U.S. space launch capability without undue cost concerns.

Today, numerous companies have significant financial investments at stake having already initiated RLV developmental programs aimed at bringing this next generation launch platform to fruition. Industry experts view RLVs as the stepping stone in building an ever more responsive, reliable, and cost effective means of reaching space. Additionally, the U.S. Air Force has partnered with two companies in developing EELV programs as an interim step in reducing launch costs into the 21st century. The secondary purpose of this paper is to review the evolving RLV industry and EELV programs and assess whether industry launch failure findings will have any impact on the technologies' future development and implementation.

Notes

[1] Agency Group 9, "Air Force Releases Space Launch Review Results," *FDCH Regulatory Intelligence Database*, (U.S. Department of the Air Force), No Date.

[2] John C. Tanner, "Politics and Other Satellite Disasters," *Telecom Asia*, August 1999, 10.

Part 2

Space Launch – Reliability Under Fire

To infinity and beyond!

— Buzz Lightyear

With over 40 years of experience as a space faring nation, complacency characterizes the average American's perception of the space launch industry. Media coverage of Space Shuttle missions exemplifies this attitude offering little more than an aside on the evening news or a few inches buried within the daily newspaper. Satellite launches fare even worse finding their coverage relegated to niche markets such as *Aviation Week & Space Technology* or the *Air Force Times*, except when a catastrophic failure occurs and generates a "newsworthy" event. This complacency, however, was rocked at the end of the 20th century when an unprecedented series of U.S. launch failures served to remind industry experts that space launch remains a risky business. It also served as an expensive reminder that the nation must focus on enhancing the reliability and safety of space launches if it intends to remain a superpower in the space realm. This chapter focuses on the launch failures of 1998 and 1999 and reviews industry analyses aimed at improving future launch capabilities.

LAUNCH FAILURES

Between 1998 and 1999, the nation was reminded of the complexities involved in achieving orbit following six launch failures in which payloads were either obliterated or left stranded in useless orbits. The failures touched every sector of the space industry, military, civil, and commercial and served to remind the nation that space launch is still a high-risk venture, but critical to ensuring a continued space presence. While potentially crippling to U.S. space preeminence, an immediate concern was the "seemingly unrelated hardware problems which caused the failures."[1]

August 12, 1998, was the start of the shake-up when a USAF/Lockheed Martin Titan IVA/Centaur carrying a $1 billion NRO Mercury signals intelligence spacecraft exploded shortly after liftoff from Cape Canaveral. The subsequent investigation blamed faulty wiring in the core vehicle's second stage as the problem. A second Titan failure occurred April 9, 1999, when a Titan IVB failed to place a $682 million Defense Support Program missile warning satellite into the desired geosynchronous orbit, instead leaving it stranded short of the mark. First and second stage separation problems, along with second stage nozzle damage, were suspected in that incident. The third straight Titan failure occurred on April 30, 1999, when a Titan IVB stranded the first USAF Milstar Block 2 communication spacecraft in a useless orbit. What stood to be the USAF's most advanced communications satellite achieved the dire distinction of being Cape Canaveral's single most expensive unmanned accident in its 50-year history of space launch operations. The combined expense for satellite ($800 million) and launcher ($433 million) totaled $1.23 billion. Lockheed Martin took the blame for an "inaccurate software load that went undetected in the software verification process."[2]

The reputation of Boeing's Delta III boosters came under question during the same period following two unsuccessful launches. On August 26, 1998, on its maiden voyage, Boeing's new Delta III exploded shortly after liftoff destroying a $140 million Hughes/PanAmSat Galaxy satellite built to provide C and Ku-band service to the United States and Caribbean. The failure was blamed on a first stage control problem. The spacecraft and booster ($85 million) were insured for $225 million.[3] Boeing's second Delta III launch ended in disaster on May 4, 1999, when Orion 3, a $145 million communications satellite, missed its geosynchronous destination and was stranded in a useless orbit following a problem in the $85 million booster. The investigation identified a problem with the Pratt & Whitney RL10B-2 engine. Ensured for $265 million, the satellite was critical to Loral's communication service expansion in the Asia-Pacific region. The company faces lost revenues pending replacement of the spacecraft, which is estimated to take at least 18 months.[4]

Lockheed Martin experienced additional launch problems with their Athena booster. Costing approximately $25 million, the boosters are designed for small payloads. Athena I can lift up to 1,750 pounds into low Earth orbit, while Athena II's capacity is 4,350 pounds.[5] On April 27, 1999, a payload shroud-separation failure left Space Imaging's Ikonos 1 commercial imagery satellite improperly deployed and rendering it useless. Ikonos 1 was slated to be the first commercial 1-meter-resolution Earth-imaging satellite. A design modification is planned to correct the deficiency for future launches.[6]

Table 1. U.S. launch failures and estimated financial losses for 1998 and 1999.

DATE	BOOSTER	PAYLOAD	PAYLOAD VALUE	ELV VALUE
August 12, 1998	Titan IVA	NRO Satellite	$1 Billion*	*Combined total
August 26, 1998	Delta III	Hughes/PanAmSat	$140 Million	$85 Million
April 9, 1999	Titan IVB	DSP Satellite	$682 Million*	*Combined total
April 27,1999	Athena II	Ikonos 1	Undisclosed	$25 Million
April 30,1999	Titan IVB	USAF Milstar	$800 Million	$433 Million
May 4, 1999	Delta III	Orion 3	$145 Million	$85 Million

LAUNCH FAILURE ASSESSMENTS

Both government and commercial sectors chartered independent and internal review teams to assess the launch failures. While specific accident causes varied from vehicle to vehicle, review findings identified four common links of a systemic nature. Of the numerous discrepancies noted, the following shortfalls were consistently identified throughout: 1.) Over emphasis on cost cutting measures; 2.) Loss of experienced personnel; 3.) Inadequate manufacturing process controls; and 4.) Insufficient oversight on quality assurance.[7]/[8]

Over emphasis on cost cutting measures was high on the list of recurring themes throughout the reports. Criticism centered on pressure from the Air Force and NASA to reduce launch costs, combined with industry's desire to make a profit. The "better, faster, cheaper" paradigm manifested itself in reduced staffing levels, diminished technical expertise (e.g., cheaper employees), and fewer procedural checks and balances. A review group appointed by Air Force Secretary F. Whitten Peters found that as the Air Force and contractors cut budgets, oversight of launches and booster manufacturing declined. The cost reductions actually drove up launch costs as reliability decreased.[9] The inaccurate software load that caused the loss of the Air Force's $1.23 billion Milstar satellite serves to illustrate the dire consequences cost-cutting measures can have.[10] Cost-cutting measures influenced the other three findings as well.

Loss of experienced personnel also received high interest in the reports. Personnel losses stemmed from several areas to include downsizing, an aging of the workforce and subsequent retirements, and a reduction in "highly paid, experienced personnel in favor of younger, equally well-credentialed (and less costly) individuals."[11] Grave concern centered on the lack of overlap between individuals retiring and younger specialists being hired as mentoring opportunities were thereby negated. As summed up by one of the independent studies, "Documentation is no substitute for having been there and done that."[12] The study emphasized that lessons-learned from the failures of the 1950s and 1960s are being lost as that generation of experts leaves the workforce. The investigation team reviewing the August 12th Titan IVA failure noted that the Air Force's downsizing of the program in preparation for its final phase-out led to a reduction in contractor oversight. Whether that reduction resulted in degradation of Titan quality is open to debate.

Personnel reductions were also cited as a reason for stretching the experienced workforce too thin, which equated to a reduction in managers' ability to provide program oversight and quality assurance. Again, implementation of "better, faster, cheaper" was criticized for being used to do away with program reviews often deemed as nuisances. The argument, however, is that the Titan IV and Delta III vehicles were built to be less complex, theoretically requiring less oversight.[13] Secretary Peters' appointed review group cited two problems relevant to this issue. The first was a "going-out-of-business attitude" toward Titan IV boosters by Air Force and contracting personnel focusing on the program's phase out even though $20 billion worth of payloads is still pending launch. Second, the group found launch supervision spread over too many Air Force agencies and contractors. With responsibility spread between Air Force Materiel Command, Air Force Space Command, the Air Force Secretary's acquisition office, and contractors, lines of accountability were obscured. The review group recommended appointing a launch control mission director to centralize responsibility.[14]

One researcher believes the government needs to hire more economists and fewer accountants, "Economists understand 'value' and accountants only understand 'price.' But price and value are not the same thing. Things that work have value. Things that fail, no matter how cheap, don't have value."[15]

THE COST OF FAILURE

The impact of launch failures is far reaching and extends beyond the obvious economic considerations. Launch failures are obviously costly in terms of lost up-front design expenditures, but they also equate to lost revenues from destroyed or improperly deployed spacecraft, satellite replacement costs, increases in insurance premiums, and costs associated with delaying subsequent launches pending accident investigations. These only highlight a few of the more definitive impacts.

In 1998, satellite insurers collected global premiums worth $950 million, but paid claims totaling more than $1.7 billion for launch and in-orbit failures.[16] Claims for 1999 were just as unbalanced. In the long run, this unbalance is translated to investors via increased premiums for all launch platforms, but particularly those deemed high risk.

Failures can also damage the financial viability, competitive position, and future growth potential of the U.S. launch industry as shaken customers search overseas for launch platforms and investors shy away from risky endeavors. RLV developers already struggling to attract private capital mourned the lack of enthusiastic investors following each subsequent launch failure.[17]

Lockheed Martin's postponement of Atlas III launches due to problems in the RL10 upper stage engine, cost the company between $85-90 million when Space Systems Loral withdrew its Telstar 7 communications satellite from the Atlas III line-up. Space Systems Loral's concern of drawn-out delays and launching their spacecraft on a vehicle tied to a failure investigation, coupled with an enticing offer from Europe's Arianespace, influenced their decision.[18]

Lockheed Martin was forced to postpone Atlas III's maiden flight launching Telstar 7 following the May 4, 1999, Delta III failure. The failure of Boeing's Delta III was blamed on a problem with the Pratt & Whitney RL10B engine and serves to demonstrate the cascading effect failures can have. With no replacement flight immediately available, Lockheed Martin will be forced to pay for unplanned launcher maintenance and upkeep, yet another hidden cost caused by the failure.[19]

NASA implemented a sweeping review of all the Agency's U.S. spacecraft scheduled for launch this year following the string of failures and loss of their Mars spacecraft. Reviews include examination of at least a dozen projects and have already delayed launches for projects such as the IMAGE satellite, designed to study the Earth's magnetosphere. Launch delays cost money and can takes months to reschedule once a spacecraft loses its place in the queue. Originally scheduled for launch February 15, 2000, it's estimated it will cost approximately $60,000 per day to maintain the satellite on the ground.[20]

While financial losses associated with launch failures are verifiable and readily measured, other losses are not so definitive. For instance, how does one measure a launch failure's impact on national security? The three Titan failures all involved national security payloads and while the government is not likely to publicly address the losses in terms of their national security impact, the fact remains an impact does exist.

Notes

[1] Craig Covault, "Titan, Delta Failures Force Sweeping Review," *AWST*, May 10, 1999, 29.

[2] Craig Covault, "Titan, Delta Failures Force Sweeping Review, " *AWST*, May 10, 1999, 28-30.

[3] Craig Covault, "Boeing Delta III Explodes; Commercial Debut Ruined," *AWST*, August 31, 1998, 23.

[4] Craig Covault, "Delta III Failure Ruins Comeback, Strands Orion," *AWST*, May 10, 1999, 30-31.

[5] Michael Mecham, "Faulty Athena Shroud Ruins Ikonos 1 Launch," *AWST*, May 3, 1999, 45.

[6] Editor, "Athena/Ikonos Loss Caused by Open Circuit," *AWST*, June 14, 1999, 82.

[7] William B. Scott, "Panel Links Launch Failures to Systemic Ills," *AWST*, September 13, 1999, 41.

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[8] Robert Wall, "Fixing Space-Launch Problems Could be Costly," *AWST*, December 6, 1999, 31.

[9] Bruce Rolfsen, "Report Blames Air Force for Launch Failures," Air Force Times, December 13, 1999, 28.

[10] William B. Scott, "Launch Failures Cripple U.S. Space Prowess," *AWST*, 3 May 1999, 31.

[11] William B. Scott, "Launch Failures Cripple U.S. Space Prowess," *AWST*, 3 May 1999, 32.

[12] William B. Scott, "Launch Failures Cripple U.S. Space Prowess," *AWST*, 3 May 1999, 32.

[13] William B. Scott, "Launch Failures Cripple U.S. Space Prowess," *AWST*, 3 May 1999, 31.

[14] Bruce Rolfsen, "Report Blames Air Force for Launch Failures," *Air Force Times*, 13 Dec 1999, 28.

[15] William B. Scott, "Launch Failures Cripple U.S. Space Prowess," *AWST*, 3 May 1999, 32.

[16] John C. Tanner, "Politics and Other Satellite Disasters," *Telecom Asia*, August 1999, 10.

[17] Joseph C. Anselmo, "RLV Ventures Strained by Funding Problems," *AWST*, 5 July 1999, 24.

[18] Craig Covault, "Delays Force Key Atlas Payload to Arianespace," *AWST*, 19 Jul 99, 25-26.

[19] Craig Covault, "Delays Force Key Atlas Payload to Arianespace," *AWST*, 19 Jul 99, 26.

[20] Washington. "NASA Review Leaves Projects on Launch Pad." *Nature*, 10 February 2000, 583.

Part 3

Reusable Launch Vehicles (RLVs)

> *Our safety as a nation may depend upon our achieving "space superiority." Several decades from now the important battles may not be sea battles or air battles, but space battles, and we should be spending a certain fraction of our national resources to insure that we do not lag in obtaining space superiority.*
>
> — Maj Gen Bernard A. Schriever, 1957

Daniel S. Goldin, NASA Administrator, challenged the space launch industry to engage in long-term vision planning with regards to space access. He additionally called for revolutionary designs in launch vehicles in order to ensure United States preeminence in space exploration.[1] His words set the tone in articulating the nation's need to develop an "on demand" space launch capability which offers responsive, reliable, and affordable space access. Industry's best hope for meeting that challenge lies with ongoing development of reusable launch vehicles (RLVs). Numerous companies currently have RLV proposals in some state of design. NASA's own hope for improving spacecraft reliability 10-100 fold within a decade rests with the X-33 project, an RLV feasibility study plagued by setbacks. This chapter focuses on RLV development considerations and reviews concepts currently under design.

RLV DEVELOMPENT CONSIDERATIONS

The U.S. Space Shuttle is the only RLV in operation today, however, since the 1986 Challenger explosion Shuttle operations have been drastically cutback and government policy prohibits the Shuttle from carrying commercial payloads. Hence, the majority of government and all of commercial payloads are delivered to orbit via expendable launch vehicles (ELVs). ELVs are expensive and range in price from $8,000 to $10,000 per pound. Current estimates deem launch costs can equate to as much as 40 percent of a project's total budget, adding millions of dollars to an already expensive endeavor.[2] A primary goal of RLV development is to significantly reduce launch costs (estimates are $1,000 per pound or less), while enhancing vehicle responsiveness and reliability. The reusability of RLVs is intended as a key cost-cutting feature.

RLV technology focuses on a launch vehicle's ability to leave the earth's surface, deliver a payload to orbit and return to earth for refitting, refueling and reuse. In other words, "a completely reusable vehicle capable of achieving earth orbit while carrying some useful payload and then returning."[3] Current developmental studies include single-stage-to-orbit (SSTO) and two-stage-to-orbit (TSTO) vehicles. Debates surround the two approaches with SSTO proponents claiming vulnerabilities inherent in multiple staging lead to increased risk, while dual-stage proponents argue SSTO is too challenging for current technologies. No one argues that RLV development pushes the limits of current capabilities. [4]

RLV developers face significant challenges in bringing this technology on-line to include developing new materials, vehicle structures, control systems, and reducing overall vehicle weight which adds to the cost of launch. Additional challenges lie in improving ascent propulsion, developing durable and lightweight thermal protection and achieving flexibility in cross-range capability to allow for touchdowns at multiple locations. [5] Experts predict dramatic reductions in launch costs would spark unprecedented growth in space industries and enable expansion of space applications, a boon for government, civil, and commercial endeavors. [6]

While developmental concepts offer a plethora of differences, from vertical versus horizontal takeoffs and landings, to glide capabilities versus rotor propulsion, the one constant in all projects is the desire to build a cost-effective mode of space lift. Hence, a fundamental design decision for all RLVs is determining the payload capability. Payload capabilities influence technical considerations and "drives the vehicle's physical size, engine performance requirements, development cost, and other attributes."[7] The value of smaller versus larger vehicles generates debate, but markets currently exist for both classes. The immediate value of smaller vehicles is that they incur less technical risk since engine performance requirements are reduced. The key to financial success will be in developing a vehicle capable of satisfying commercial, civil, and governmental requirements.

The debate centers on whether a smaller vehicle can meet civil and government requirements with regards to space station lift requirements and national security payloads. NASA needs a responsive, reliable lift capability to support space station operations, while the nation's increasing reliance on space superiority is driving spacecraft operational considerations over the next decade and beyond. Opponents of larger vehicles believe that allowing advancement of a smaller vehicle sets the stage for increased payload capabilities at a later date as technology matures and undergoes refinement. Others recommend reducing larger payloads by "taking advantage of miniaturization or by assembling modular components in orbit." [8]

Take-off and landing parameters also affect operations and impact not only design costs, but also long term infrastructure expenses. Horizontal liftoffs and landings require operational runways, with attending maintenance, and even vertical lift vehicles require specially built platforms. Combination launchers proposing vertical lift and horizontal landing will require both infrastructures.[9]

RLV maneuverability, to include cross-range capability (maneuvering in the atmosphere upon returning from space), does offer several advantages, including operational capabilities and flexibility in basing locations. With respect to operational capabilities, immediate benefits of cross-range allow for controlled abort maneuvers during emergencies. Long-term capabilities offer the potential of "space lift," allowing for "earth-to-orbit, orbit-to-earth, and intraspace transportation."[10] Commercial and military applications for this capability abound. Additionally, intraspace transportation would redefine the Air Force's core competency of "rapid global mobility."[11]

Maneuverability and cross-range of RLVs also allow for flexibility in selecting operational locations. Expendable launch vehicles favored liftoff sites situated near oceans in order to allow fuel tanks and other debris, to include catastrophic failures, to fall harmlessly back to the earth's surface. Maneuverable RLVs theoretically negate this concern. This characteristic is already fueling a "space port race" within the U.S. as states such as Texas, Alaska, Idaho, Utah, Washington, Oregon and Montana vie to attract space launch industries. Montana is seeking to attract the NASA/Lockheed Martin VentureStar program, which offers 300 employment positions. Montana touts not only its prime location, which offers cheaper access to northern and polar orbits due to its high altitude and high latitude, but also the state's wide open spaces and low population density. Additionally, Montanans note the favorable weather their state has to offer, significantly free of hurricane threats. Other competitors cite similar benefits with an additional focus on quality of life aspects for employees.[12]

Other developmental considerations include turn-around times and vehicle life expectancy. Today's expendable launch vehicles require months of preparation prior to liftoff and have a life expectancy of one mission. The speed with which an RLV can be retrieved and refitted for subsequent missions will play a key role in its commercial viability. Additionally, maximizing vehicle longevity and annual launch capability, while reducing overall maintenance requirements, will enhance efficiency for customers and profits for investors.[13]

Final RLV considerations for discussion here include weatherability and crew requirements. Weather limitations caused by lightening, winds, and rains, impose frequent strains on launch operations and equate to costly delays. An RLV's ability to overcome weather limitations will enhance its competitive status. Of course, the flexibility discussed above in terms of selecting operating locations may allow for more "weather friendly" launch environments.

Another consideration is crew requirements. This takes into account both the number of individuals necessary to support operations, ground processing, flight operations, and support personnel, and whether the RLV is manned or unmanned during flight. Today's expendable launch vehicles require hundreds of support personnel to oversee and manage operations, while the Space Shuttle employs thousands of individuals. A cost-effective RLV will require enhanced reliability in order to reduce manpower overhead and associated expenses. One estimate recommends support operations be limited to no more than 100 individuals.[14]

A few developmental RLVs are planned as manned vehicles, developed with an eye towards replacing cost prohibitive Shuttle operations down the road. The very nature of manned RLVs drives up developmental and operational costs as the Shuttle so aptly demonstrates. Originally envisioned as a means of inexpensive space lift based on its reusability and planned usage rates (50 per year), the Shuttle quickly fell short of optimistic goals. While its human occupants have proven indispensable during missions such as satellite pre-deployment troubleshooting, life science experiments, and on-orbit satellite retrieval and maintenance, the fact remains their presence comes at a price. Costs rise sharply based on requirements for higher reliability rates, which require engineers to "build extra levels of redundancy, additional design margins, and new safety oriented design systems...(in addition) to many subsystems specifically dedicated to supporting the human cargo," including crew compartments, life-support subsystems, and environmental controls.[15] These additional hardware requirements also translate into additional weight requirements thereby increasing subsequent launch costs. Recent estimates place Shuttle operations around $400 million per mission depending on the objective.[16] The additional life support, safety, weight requirements and complexity inherent in developing vehicles with manned capabilities will have an impact on their affordability.

The strength of the U.S. space program rests on its ability to reliably deliver payloads to orbit. The 1998 and 1999 launch failures seriously impacted that ability and shook the U.S. space industry's foundations. Those failures highlighted the need for responsive, reliable, and affordable space access, the qualities which RLV developers hope to deliver. But RLVs bring their own set of liabilities to the launch pad. As reusable systems, their cost effectiveness is heavily dependent on short turn-around times and high launch rates. Their infrastructure of operational support personnel must be continuously maintained, which is another reason to limit crew requirements. High launch rates, in turn, require a large customer base. Affordability and reliability will be crucial to attracting payloads and ensuring continuos usage demands.[17]

RLV DEVELOPMENTAL CONCEPTS

The one-time-use of conventional rockets is one reason for their prohibitive cost. These expendable vehicles are built, loaded with fuel, sent into space, and then left to burn-up on reentry into the atmosphere. Commercial investors are looking to RLVs to reduce launch costs and spur economic development in the space industry by making orbital access routine and affordable. The intrinsic value of RLVs lies not only in their reusable nature, but also in the added reassurance of a proven entity—their payloads made it to orbit and they returned to tell the tale.

Several U.S. companies are currently involved in developing RLVs (Table 2). Some are strictly commercial ventures, while others are joint government/commercial undertakings seeking to combine resources and knowledge. The most notable joint venture is the NASA and Lockheed Martin X-33, VentureStar. NASA's interest in RLV development is twofold, centering on its desire to pursue ongoing space exploration, in addition to seeking a reliable and cost-effective cargo delivery and retrieval system for the International Space Station. In conjunction with Lockheed Martin, NASA is developing the X-33 as an experimental vertical take-off, SSTO vehicle. "The X-33 is a roughly half-sized experimental craft intended to test a type of rocket engine known as a linear aerospike, as well as other technologies." Theoretically the linear aerospike will be able to power an RLV into orbit while automatically adapting to atmospheric pressure. VentureStar is a feasibility study designed to assist NASA in making a determination as to the appropriate time to phase out reliance on the Space Shuttle.[18] However, the venture has been plagued by technological challenges, which have adversely impacted test schedules and budgets, leading to operational overruns in excess of $300 million.[19]

Among private ventures, Kistler Aerospace leads the way in financing with development of the K-1. A TSTO concept using Russian-built engines, the K-1 design calls for return of the first stage directly to the launch site, while the second stage orbits earth prior to return. Both stages would re-deploy using parachutes and land on inflatable air bags.[20] Kistler raised over $500 million for initial research, but has had difficulty raising additional funds due to investor concerns industry-wide following the 1998 and 1999 launch failures and recent Iridium bankruptcy.[21]

Another innovative approach is Pioneer Rocketplane's two-seater, horizontal takeoff vehicle, designed with a small shuttle-style cargo bay for its payload and second stage. Current design specifications call for a length of 87 feet and a wingspan of 44 feet. The design calls for a runway takeoff, powered by conventional turbofan engines, following which the vehicle joins a tanker at approximately 20,000 feet for aerial fueling of 140,000 pounds of liquid oxygen. Once fueled, a single RD-120 rocket would be fired boosting the vehicle to Mach 15 and 70-nautical-miles where it would release the payload and second stage. The piloted vehicle would then return to Earth.[22]/[23]

Space Access LLC is also designing a crewed, multi-staged, horizontal take-off vehicle powered by a patented engine design known as an ejector ramjet. Ground tests have demonstrated the ejector ramjet engine capable of propelling the craft from a standstill to Mach 6. The developmental concept calls for the space plane to meet stringent "FAA Part 25 criteria—modified for space operations—which covers airworthiness design of transport aircraft."[24] The vehicle has a three-stage design with all stages returning to the launch site via wings.[25]

Rotary Rocket's manned, SSTO vehicle is designed for vertical take-off and landing. Known as the Roton, the vehicle's innovative, revolutionary engine design is theoretically capable of propelling the vehicle all the way to orbit, after which it would descend to earth on foldaway helicopter blades. [26] The company is reducing developmental costs associated with manned vehicles by limiting creature comforts. According to Geoffrey V. Hughes, vice president for sales and marketing, "The life-support (concern) is overrated. We're not giving these guys a shirtsleeve environment and zero-gravity toilets."[27]

Universal Space Lines is also developing an RLV certificated to aircraft standards. Their crewed, TSTO vehicle design calls for a vertical takeoff/vertical landing capability. The company envisions the SpaceClipper filling the space tourism and expedient point-to-point transportation markets. Operational capability is projected for 2008 or 2009.[28]

Kelly Space & Technology's RLV is known as Astroliner. The design is based on a towed – launch concept of operation, like that of a glider. A Boeing 747 would tow the TSTO vehicle from a runway and release it at high altitude. The Astroliner would then be propelled into orbit via a built-in rocket.[29]

While financial backing remains a major impediment to RLV development, another resides with technological break-throughs. RLV technology pushes the limits of existing science and is heavily dependent on maturation and innovation. These two obstacles are working together to delay implementation of a fully operational vehicle. While companies such as Pioneer Rocketplane, Space Access, and Universal Space Lines project test flights between 2001 and 2004, industry experts don't envision an initial operating capability until 2010, at the earliest.[30]/[31]

Table 2. List of U.S. companies developing RLVs.

COMPANY	REUSABLE LAUNCH VEHICLE
Boeing	TSTO with a crew transfer vehicle for ISS
Bristol Spaceplanes Ltd.	Ascender
Kelly Space & Technology	Astroliner
Kistler Aerospace	K-1
Lockheed Martin (in conjunction w/ NASA)	X-33, Venture Star
NASA	X-38 (Space Station Lifeboat) X-34 (Small Booster)
Orbital Sciences Corporation	TSTO with a crew "Space Taxi"
Pioneer Rocketplane Corporation	Pathfinder
Rotary Rocket Corporation	Roton
Space Access LLC	Space plane
Universal Space Lines	SpaceClipper

Notes

[1] Joseph C. Anselmo, "NASA Chief Rips Industry, Urges New Design Path," *AWST*, 10 May 99, 20.

[2] Space Vest, *State of the Space Industry1997 Outlook*, (Virginia: Space Vest, 1997), 35-36.

[3] Maj Michael A. Rampino, *Concepts of Operations for a Reusable Launch Vehicle*, (Alabama: Air University Press, 1997), 7.

[4] Joseph C. Anselmo, "NASA Chief Rips Industry, Urges New Design Path," *AWST*, 10 May 99, 20.

[5] Joseph C. Anselmo, "NASA Chief Rips Industry, Urges New Design Path," *AWST*, 10 May 99, 20.

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Part 4

Evolved Expendable Launch Vehicles (EELVs)

> *Just as the oceans opened up a new world for Clipper ships and Yankee traders, space holds enormous potential for commerce today. The market for space transportation could surpass our capacity to develop it.*
>
> — Ronald Reagan

With fully functional RLVs not anticipated until the 2010 timeframe, more immediate improvements in domestic launch capabilities are envisioned with the evolved expendable launch vehicles (EELV) under development by the U.S. Air Force in conjunction with Lockheed Martin Corporation and The Boeing Corporation. An outgrowth of the 1994 Space Launch Modernization Plan, the EELV concept seeks to reduce launch costs and enhance reliability by standardizing processes, procedures, support equipment and infrastructures. The current lack of standardization among launch vehicles equates to "each mission (being) unique, making access to space unnecessarily expensive."[1] This chapter focuses on EELV development and reviews concepts currently under design.

EELV BACKGROUND

Two primary goals of the Air Force's EELV initiative were to reduce launch costs and implement acquisition reform.[2] Originally planning to select one EELV contractor, in 1997 the Air Force changed its strategy when industry analysis of projected launch demands indicated significant increases in commercial demands, over military requirements, through 2010. The modification was a windfall for the Air Force in two ways. First, it allowed for the development of two vehicles instead of one, and second, it allowed the Air Force to share only a portion of development costs vice paying all expenses, which was the original approach. Then Acting Secretary of the Air Force F. Whitten Peters awarded the contracts in October 1998 commenting, "Today, with the award of EELV contracts, we are entering a new and exciting era where government and industry have pooled their resources in order to serve a combined military and commercial market."[3] The dual contractor approach is expected to "capitalize on the benefits of competition,"[4] while spreading costs between military and commercial customers is expected to enhance the nation's overall competitiveness in the worldwide launch market.[5]

Lockheed Martin and Boeing each received two contracts with a combined value of $3.03 billion. Each company received a $500 million contract to offset EELV development costs in addition to contracts for future launch services to include Air Force and National Reconnaissance Organization (NRO) satellites. Boeing took the lead in launch service contracts receiving $1.38 billion for 19 government launches between 2002 and 2006. Lockheed received $650 million to cover nine launches during the same timeframe.[6] Initial EELV launches are projected as early as 2001 and will carry commercial payloads.[7]

EELVs are projected to reduce launch costs by as much as 25 to 50 percent.[8] Reviewing cost comparisons, official estimates determined it would cost in excess of $20 billion to use existing launch vehicles to deliver national payloads to orbit through 2020. Estimates predict those same payloads could be delivered using EELVs for approximately $13.8 billion.[9]

A secondary goal of the EELV program, acquisition reform manifested itself in the Air Force establishing contractor requirements vice telling contractors how to build EELVs.[10] The Air Force laid down several requirements contractors must comply with when developing

EELVs to include ensuring vehicle reliability and use of launchers by both defense and commercial payloads.[11]

This approach was designed to translate into reduced contractor oversight, and subsequent cost savings; however, that changed following publication of the 1998 and 1999 launch failure reviews. In order to enhance quality assurance oversight, the Air Force now intends to establish an engineering oversight team to work with EELV contractors. In addition, the Air Force intends to appoint a director for each launch mission thereby implementing a review finding recommendation and mirroring similar procedures established by the NRO and commercial customers.[12]

Designed to transition the expendable launch vehicle industry into the 21st century, the EELV program promises to reenergize the domestic space launch market following the failures of 1998 and 1999 by offering affordable, reliable launch capabilities built on existing technological foundations. It also promises to initiate a new era for military space launch as the Defense Department transitions from having an organic launch capability to purchasing launch services on the open market.

EELV DEVELOPMENT CONCEPTS

In its effort to build a family of launch vehicles, the Air Force has mandated a few specific requirements for EELV developers to ensure standardization and thereby enhance cost reductions. Key among these is the requirement for a standardized payload carrier and the ability to use a standard launch pad. The Air Force is requiring contractors to use Cape Canaveral Air Station, Florida, and Vandenberg Air Force Base, California, as dedicated launch sites. Beyond these requirements, Lockheed Martin and Boeing have varied approaches to EELVs.[13]

Lockheed Martin's family of three Atlas V launchers are derivatives of current company vehicles including the Atlas booster's liquid oxygen-kerosene propulsion, and the Titan's rigid construction design. A RD-180 engine will power the Atlas V. Pratt & Whitney will build the engines in the U.S. for Defense Department payloads, while Russian-built engines will carry commercial payloads. The choice of the RD-180 engine allowed for tradeoffs making the Atlas V "faster and less expensive to manufacture because of its simpler design." The heavy booster will be capable of launching payloads up to 29,000 pounds to geosynchronous transfer orbit. Atlas V vehicles will be built at Lockheed Martin's upgraded Littleton, Colorado, facility and flown to launch sites. The company predicts a production capability of 20 vehicles per year.[14] A major emphasis in ongoing EELV development will be aimed at additional cost-cutting measures. Current estimates predict the Atlas V will cut launch costs by almost 50 percent.[15] However, the company received a "wake-up call" following Boeing's contract for twice as many launches, a decision driven by cost factors according to Lockheed Martin.[16]

Boeing's Delta IV borrowed numerous construction designs from Delta II and III, but will showcase a new cryogenic first stage using the RS-68 engine built by Rocketdyne. The five Delta IV models boast a 90-95 percent common hardware rate. The Delta IV heavy booster will be capable of launching payloads up to 28,950 pounds to geosynchronous transfer orbit. The company invested in a new production facility in Decatur, Alabama, and intends to transfer completed common booster cores to launch sites via water transit. The new facility allows for common booster cores to be built from the ground up at one location, a departure from current Delta vehicles where construction encompasses as many as five locations spread throughout California, Colorado and Canada. This dispersed production trail equates to a 25-30 month production cycle for current Delta vehicles. Alabama's single-site construction facility will significantly reduce production time with start to finish estimates of 6-7 months. Boeing anticipates a production capability of 40 common booster cores per year.[17]

Reliant on existing technologies, rather than technological breakthroughs, the Atlas V and Delta IV vehicles offer the U.S. commercial launch industry a solid foundation as the nation enters the 21st century and serve as a bridge between today's antiquated launch systems and the next decade's RLVs.

Notes

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Part 5

Is the U.S. Launch Program Ready for the 21st Century?

> *The United States and the Western World have an exciting and vital future in space activities of all kinds. The key to that future, be it in security activities, in scientific exploration, or in commercial exploitation, the key is responsive and cost-effective space transportation.*
>
> — Lt Gen James A. Abrahamson

The 1998 and 1999 series of launch failures raised doubts as to whether the U.S. can maintain its position as a "space power" into the 21st century. Without the ability to reach orbit on demand, this preeminent status will quickly slip away as competition in the international arena grows. Today only four countries have commercial space launch capabilities, the U.S., Russia, France and China, but as technology matures and evolves, and international cooperation blossoms, the number is likely to increase. [1] The fact remains that for Americans in particular, space is now a major factor in day-to-day living both from the view of creature comforts and national security. It affords Americans conveniences such as cellar phones and Direct-TV and serves as a force multiplier and enabler for our military forces. As reliance on space capabilities continues to grow, the U.S. must develop a solid space infrastructure capable of meeting both launch and exploration demands, without sacrificing quality, reliability and affordability.

The launch failures of 1998 and 1999 served as a wake-up call to an industry rallying around the "better, faster, cheaper" mantra. Independent and internal investigative teams consistently recommended returning to the basics in the form of solid financial foundations with less emphasis on the "bottom line," establishing mentoring and succession programs to glean lessons learned from time-bred experience, and relying on tested and proven quality control and oversight management tools. "Rockets are not like an old aircraft, where a whole subsystem can be replaced with a new one. It's very integrated. Over time and with experience" people learned what worked.[2]

While space launch is an extremely complicated endeavor, requiring technologies capable of operating in environments of "high temperatures, pressures, velocities and vibration levels," insiders, investors and insurers have grown weary of launch unreliability after 40 years of experience. Private investors have become leery of sinking financial commitments into such risky endeavors. "If aircraft had continued to fall from the sky with the same frequency as launchers some 40 years after Wilbur and Orville Wright opened the aircraft age, international mass tourism would probably still be science fiction."[3] The industry needs to embrace the review committee findings in order to elevate their status in the eyes of much needed and much coveted investors, not to mention enhancing their own space launch capabilities.

Today, cost continues to be the single most important barrier to space exploration and has close ties to reliability and responsiveness. RLV and EELV programs offer break-throughs in this arena and should be fully supported through government, civil and private investments. NASA has taken a giant step in encouraging RLV development through its Space Transportation Architecture Program wherein billions of dollars will be committed to private companies developing RLVs. This funding will assist the entire industry in overcoming the daunting technological challenges faced in developing the capability.[4] Likewise, government and industry joint investments in EELVs are crucial to its development. The 1998 and 1999 launch failures continued to reinforce the lesson already learned from the 1986 Challenger accident. The U.S.

can not afford to rely on a single mode of transportation into space. A healthy, diversified space launch capability needs to include expendable, reusable, manned and unmanned vehicles in order to support the unique requirements of space exploration. Space launch is the economic center of gravity for the entire industry. "Space on Demand" needs to be the rallying cry as the U.S. space industry enters the 21st century.

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