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Concepts of Operations for a Reusable Launch Vehicle

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Abstract

The United States is embarked on a journey toward maturity as a spacefaring nation. One key step along the way is development of a reusable launch vehicle (RLV). The most recent National Space Transportation Policy (August 1994) assigned improvement and evolution of current expendable launch vehicles to the Department of Defense while National Aeronautical Space Administration (NASA) is responsible for working with industry on demonstrating RLV technology. The purpose of this study is to help ensure the US military, especially the USAF, is prepared to take advantage of RLVs should the NASA-led effort to develop an RLV demonstrator prove successful. The focus of this study is an explanation of how the US military could use RLVs, by describing and analyzing two concepts of operations.

Four major conclusions resulted from the analysis. First, RLVs have military potential. They can perform a variety of missions including responsive spacelift, reconnaissance, and strike. However, the economic feasibility of using RLVs for earth-to-earth transportation is questionable. Second, design choices for an operational RLV will have effects on risk, cost, capability, and operations efficiency. Trade-offs will have to be made between NASA, commercial, and military requirements if all three parties are to use the same fleet of RLVs. Third, increased investment in propulsion technology development is warranted to ensure success. Fourth, the top priority for the RLV program, even from the military's perspective, should remain cheap and responsive access to space.

The research led to three recommendations. First, the US military should become a more active participant in the RLV program to ensure its requirements are defined and incorporated. Second, America should not pursue development of operational RLVs before the technology is ready. Third, it is not too early for the US military to think deeply about the implications of operational RLVs for war-fighting strategy, force structure planning, training, and doctrine.

About the Author

Maj Michael A. Rampino (BS, United States Air Force Academy; MS, Air Force Institute of Technology) was commissioned upon graduation from the United States Air Force Academy in 1983. Graduating from the Signals Intelligence Officers Course in November 1983, he went on to perform intelligence operations crew duty. Following completion of graduate school, he was assigned as a staff officer in the space operations directorate of Electronic Security Command headquarters. He was then selected to command a space surveillance detachment, establishing a new unit and mission for Air Force Space Command at Osan Air Base, Republic of Korea. Upon return from overseas duty, he became the director of requirements for the 45th Space Wing and, subsequently, the chief of standardization and evaluation for the 45th Operations Group, charged with standardizing and evaluating USAF spacelift and range operations at Cape Canaveral, Florida, and the Eastern Range. Major Rampino is a graduate of Air Command and Staff College, a 1996 graduate of the School of Advanced Airpower Studies and in July 1996 was assigned to the Joint Staff.

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Chapter 1

Introduction

The objective of NASA's technology demonstration effort is to support government and private sector decisions by the end of this decade on development of an operational next-generation reusable launch system.

The objective of DoD's effort to improve and evolve current ELVs is to reduce costs while improving reliability, operability, responsiveness, and safety.

The United States Government is committed to encouraging a viable commercial U.S. space transportation industry.

US National Space Transportation Policy
5 August 1994

Introduction

On 18 May 1996, America took another small step toward maturity as a spacefaring nation. Under the scorching sun of the New Mexico desert, an attentive media corps readied their cameras. Ground and flight crews monitored consoles and waited for the latest global positioning updates to be received and processed. At 0812:02, a small, pyramid-shaped rocket, the McDonnell Douglas Aerospace DC-XA, rose from its launch mount on a column of smoke and fire. Unlike today's operational spaceships, this one landed on its feet after a 61-second flight with all its components intact. This ninth flight of the Delta Clipper experimental rocket was no giant leap for mankind given the limited capabilities of the vehicle, but it proved once again that reusable rockets are a reality—today.[1]

Purpose. The US military must be prepared to take advantage of reusable launch vehicles (RLV) should the National Aeronautical Space Administration (NASA)-industry effort to develop an RLV technology demonstrator prove successful.[2] The focus of this study is an explanation of how the US military could use RLVs, by describing and analyzing two alternative concepts of operations (CONOPS).

Background. The most recent National Space Transportation Policy assigned the lead role in evolving today's expendable launch vehicles (ELV) to the Department of Defense (DOD). It assigned NASA the lead role in working with industry on RLVs.[3] The United States Air Force (USAF), as the lead spacelift acquisition agent within the DOD, is an active participant in RLV development but with limited responsibility and authority since it is a NASA-led program.[4] USAF leadership has maintained interest in the program but has focused on ensuring continued access to space without incurring the technical

risk of relying on RLV development. The USAF's initiation of the evolved expendable launch vehicle (EELV) program reflects this approach.[5]

As of this writing, the USAF, on behalf of DOD, is formulating and defining DOD requirements for an RLV in an effort to plan for a possible transition from ELVs to RLVs. Specifically, the NASA-USAF integrated product team (IPT) for Space Launch Activities is currently examining "operational RLV DOD requirements."[6] In addition, the USAF's Phillips Laboratory started a Military Spaceplane Applications Working Group in August 1995 which may indirectly help identify DOD's RLV needs.[7] This research is intended to contribute to the ongoing process by describing how the US military should use RLVs.

Research Question. In order to help remedy the lack of specific DOD requirements for an operational RLV, this study identifies CONOPS for military use of such a vehicle. Obviously, identifying CONOPS requires addressing other issues along the way. For instance, the attributes of an operational RLV must first be identified to facilitate development of the alternative CONOPS. If there are new missions enabled by the vehicle's reusable nature, missions which are not feasible using ELVs or the Space Transportation System (STS) (also known as the shuttle), they must be identified as well. Given the timeline of the RLV program, the year 2012 is a reasonable estimated date for the fielding of an operational system. This date will serve as the basis for analysis in this study.

Assumptions. Four assumptions are worth mentioning at the outset. First, the estimate that RLV technology could become operationally feasible by 2012 is reasonable. Second, a fiscally constrained environment will continue. Third, the US government will continue to support growth and development of the US commercial spacelift industry and encourage dual-use, or perhaps triple-use, of related facilities and systems.[8] Fourth, the US government's national security strategy will continue to emphasize international leadership and engagement to further American political, economic, and security objectives.

Given the assumptions of fiscal constraint and a government policy of cooperation with and encouragement of the US commercial spacelift industry, any military RLV acquisition strategy will do well to take maximum advantage of possible dual-use or triple-use opportunities and economies of scale. For instance, the US military could pursue development of a military RLV which would share design similarities (i.e., hardware components) with commercial RLVs to the greatest practical extent, minimizing military-unique design requirements and thereby lowering costs. Such an approach would also take advantage of the economies of scale possible if the commercial spacelift industry were to operate an RLV similar to the one manufactured for the military. Of course, this assumes there is a need for a military-unique RLV—not just military use of a commercially produced and operated RLV.

Military RLV Requirements

One answer to the research question proposed earlier might be that the DOD does not need RLVs. There may be no requirement for them. One way to

confirm or deny this assertion is to examine the relevant requirements documentation.

Spacelift Requirements. An Air Force Space Command briefing on mission area plan (MAP) alignments and definitions lists four functions for a "reusable spacecraft for military ops": strike, transport, space recovery, and reconnaissance.[9] However, the most recent spacelift MAP takes a more conservative approach. Using the strategies-to-tasks methodology, the MAP documents five tasks of spacelift derived through the mission area assessment process: launching spacecraft, employing the ranges to support these launches, performing transspace operations, recovering space assets, and planning and forecasting government and commercial launches.[10] Prioritized spacelift deficiencies are determined through mission needs analysis. These nine deficiencies are mainly cost-related concerns but also include two capability related deficiencies: "cannot perform transspace operations," and "no DoD capability to perform recovery and return."[11] The mission solution analysis concludes that the EELV is the number one priority in the midterm (within 10 years) although RLVs, orbital transfer vehicles (OTV), and a space-based range system are desirable in the long term (within 25 years).[12] The five key spacelift solutions are developing the EELV, completing range upgrades, cooperating with NASA in their RLV program, developing advanced expendable and reusable upper stage systems, and fielding space-based range systems.[13] Although potential RLV applications in other mission areas such as reconnaissance and strike are discussed, these are seen as long-term (10–25 years) capabilities.

The fact that the USAF's MAP for spacelift (DOD's by default) does not aggressively pursue the potential of RLVs is not surprising. Being based on the strategies-to-task framework, the MAP process will not identify a deficiency or state a requirement when there is no existing higher-level objective or task calling for a capability. Further, the National Space Transportation Policy clearly identifies NASA as the lead agency for RLV technology demonstration, not the DOD (USAF). Finally, the USAF's low-risk approach is understandable given the very real need to ensure continued access to space in support of national security requirements. The last time our country put all of its spacelift eggs in one basket, the STS, major disruptions in access to space for national security payloads resulted when the basket broke. The 1986 *Challenger* accident combined with our national policy to emphasize use of the STS over expendable launch vehicles created a situation USAF spacelift leaders never want to see repeated.[14] Given these factors, it is laudable that the spacelift MAP identifies transspace operations and recovery and return as capability deficiencies and foresees the use of RLVs in reconnaissance and strike missions. These two deficiencies will not be satisfied by EELV development, but they could be used to derive requirements for military use of an RLV.

Commander in Chief, US SPACE Command Desires. It is interesting to note that a different approach to generating requirements, a revolutionary planning approach, has identified RLVs as promising for broader military

applications and sparked the interest of America's most senior military space commander.[15] In a 1995 message discussing implementation of the conclusions and recommendations of the Air Force Scientific Advisory Board's *New World Vistas* study, Gen Joseph W. Ashy, commander in chief of United States Space Command (CINCSPACE) and commander of Air Force Space Command, identified reusable launch vehicles as one of the most important technologies cited in the findings of this revolutionary planning effort. General Ashy identified the capabilities to "take-off on demand, overfly any location in the world in approximately one hour and return and land within two hours at the take-off base" as desirable. He further suggested reconnaissance, surveillance, and precision employment of weapons as potential RLV applications.[16]

Requirements Identified. For the purpose of exploring military RLV concept of operations, this study identifies spacecraft launch and recovery, transspace operations, strike (in and from space), and reconnaissance as potential RLV tasks. The first two tasks flow from the spacelift MAP. The second two tasks are not identified as tasks for spacelift in the MAP, probably because of the inherent near-term emphasis of the MAP, but may prove feasible with RLVs. Further, as shown above, they have been identified as potential RLV applications by the CINCSPACE.

Project Overview

Before developing and analyzing CONOPS for military use of RLVs, current RLV concepts and attributes are summarized and hypothetical attributes of a notional RLV for use in military applications are suggested in chapter 2. Identifying these notional RLV attributes is a necessary step in the process of answering the research question; they are not intended to be the final word on military RLV design. Following the discussion of RLV concepts and attributes, chapter 3 presents two CONOPS. The two operations concepts are intended roughly to represent military space plane advocates' visions in the first case and to be a logical extension of the current RLV program's goals in the second case. An analysis of these concepts of operations is provided in chapter 4. The criteria used in the analysis include capability, cost, operations efficiency and effectiveness, and politics. Chapter 5 summarizes significant conclusions and recommends a course of action for the US military to pursue with respect to RLVs.

Notes

1. Maj Michael A. Rampino, personal observations of DC-XA flight test number nine, White Sands Missile Range, N.Mex., 18 May 1996. The DC-XA could hardly be called a spaceship given its limited altitude capability—the ninth flight only went to 800 feet and it never climbed above 10,000 feet. It also lacks any payload carrying capability. However, it does prove a point about the feasibility of performing reusable rocket operations.

2. For an overview of the program, see the following sources. "RLV Program Overview," Marshall Space Flight Center, Huntsville, Ala., October 1995, n.p., on-line, Internet, available from http://rlv.msfc.nasa.gov/RLV_HTMLs/RLVOverview.html. "A Draft Cooperative Agreement Notice, X-33 Phase II: Design and Demonstration," Marshall Space Flight Center, 14 December 1995, on-line, Internet, available from http://procure.msfc.nasa.gov/pub/solicit/can_8_3/.

3. Office of Science and Technology Policy, National Space Transportation Policy Fact Sheet (Washington, D.C.: White House Press Release, 5 August 1994), 3–4.

4. Maj Victor Villhard, staff officer, secretary of the Air Force, Space Policy Office, telephone interview with author, 27 November 1995. According to Major Villhard, the USAF and NASA have an ongoing cooperative effort with seven IPTs examining areas for improved efficiency in space operations. One of these teams, the spacelift activities IPT, has a panel for the express purpose of interchange and cooperation on the subject of reusable launch vehicles.

5. Col Eric Anderson, director of spacelift acquisition, assistant secretary of the Air Force for acquisition (SAF/AQSL), Pentagon, interviewed by author during visit to Marshall Space Flight Center, Huntsville, Ala., 11 December 1995.

6. Integrated Product Team for Space Launch Activities, *Terms of Reference*, draft, undated. USAF officers on the IPT encouraged this research effort to help satisfy the very real need to identify DOD requirements.

7. "Air Force Forms Study Group on SSTO," *Military Space* 13, no. 2 (22 January 1996): 4.

8. Michael K. French, "Industry Officials Cautiously Applaud Tax-Break Bill," *Space News* 7, no. 10 (11–17 March 1996): 15. The term *dual use* refers to the idea of government and commercial entities using the same system or facility. The term *triple use* is of more recent origin and has become popular to emphasize that both civil and defense government agencies use a system or facility along with commercial entities. A recent manifestation of this government policy was a proposal to create tax breaks for commercial space ventures.

9. Directorate of Plans, Air Force Space Command, "FY96 MAP Alignments and Definitions," briefing, Air Force Space Command Headquarters, Peterson Air Force Base (AFB), Colo., 23 January 1996.

10. Directorate of Plans, Air Force Space Command, *Spacelift Mission Area Plan*, 1 December 1995, 20–23 and 28. Transspace operations as described in the MAP "are those that occur in the boundary regions between the atmosphere and space." These operations involve moving people and material to and through space. See also Glenn A. Kent, *A Framework for Defense Planning*, R-3721-AF/OSD (Santa Monica, Calif.: RAND, 1989), 1. Strategies to task is "a force planning process that focuses on the building blocks of *operational capability* . . . clearly linking national security objectives to the timely procurement of hardware."

11. *Spacelift Mission Area Plan*, 32. The cost-related deficiencies are the high recurring operations and maintenance costs of launch vehicle infrastructure and the ranges; the operability concerns stemming from spacelift's manpower intensiveness and long launch preparation times; long-range turnaround times; the poor supportability resulting from nonstandard ranges; the ranges inability to support all users; and the difficulty DOD has in identifying and validating the growing commercial sector requirements.

12. *Spacelift Mission Area Plan*, 36, 85. Space-based range system refers to replacing the ground- and air-based radar, telemetry receivers, tracking, and command systems now used in support of spacelift operations with space-based systems. For example, some spacelift operations depend on support from aircraft to collect telemetry when the launch vehicle is not in view of a ground station. It may be possible to use a satellite to collect this information. Using a satellite instead of the aircraft may be cheaper, more reliable, and more flexible.

13. *Spacelift Mission Area Plan*, iii.

14. This accident is a theme consistently heard by the author during discussions with USAF officers involved in spacelift policy, operations, and acquisition business. At least one author has claimed the USAF's emphasis on expendable launch vehicles has more to do with its organizational essence and intercontinental ballistic missile heritage. If there is any truth to this it would certainly be hard to prove. It would be even harder to prove its relevance given the strong evidence of rational reasons for the USAF to pursue its current course. See Maj William W. Bruner III, "National Security Implications of Inexpensive Space Access" (master's thesis, School of Advanced Airpower Studies, Maxwell AFB, Ala., June 1995).

15. USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century,* Summary Volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995). The USAF Scientific Advisory Board's recently published *New World Vistas* study is one example of revolutionary planning effort. It was specifically designed by the USAF as an external complement to the USAF modernization planning process due to the recognized limitations of a strategies-to-tasks approach to acquisition.

16. Message,, 221435Z DEC 95, commander, Air Force Space Command, to vice chief of staff, USAF, commander, Air Force Materiel Command, and commander, Air Combat Command, 22 December 1995.

Chapter 2

RLV Concepts and Attributes

Introduction

In order to facilitate CONOPS development and analysis, this chapter summarizes current RLV concepts and attributes and suggests hypothetical attributes of a notional RLV for use in military applications. These notional RLV attributes are not intended to serve as the final word on RLV design, as an endorsement of any particular company's concept, or as a recommendation regarding whether an RLV should take off or land vertically or horizontally. Describing the attributes of an RLV is simply required to provide a basis for the subsequent analysis. Before stating these attributes, this section first presents an overview of the three RLV concepts proposed by Lockheed Advanced Development Company (LADC), McDonnell Douglas Aerospace (MDA), and Rockwell Space Systems Division (RSSD), as well as the Black Horse transatmospheric vehicle (TAV) concept made popular by Air University's *SPACECAST 2020* project. Next, RLV attributes are discussed in terms of the requirements introduced earlier. Finally, the attributes of a notional RLV to be used for further analysis are presented.

Representative RLV Concepts

Definitions. The lexicon associated with RLVs can be confusing. Often, the term *RLV* is used interchangeably with terms like *SSTO*, for *single-stage-to-orbit*; *TAV*, for transatmospheric vehicle; and *MSP*, for *military spaceplane*. Unfortunately, there doesn't appear to be a consensus that these terms are interchangeable. RLV is not interchangeable with SSTO. A one-piece expendable rocket might also achieve orbit with a single stage, and a completely reusable multistage vehicle could be constructed. TAV tends to be used in connection with winged, aircraft-like vehicles that operate substantially in the atmosphere while maintaining some capability to reach orbit. MSP appears to be more general, including RLVs and TAVs used for military applications. For the sake of clarity, RLV will be used here to refer to a completely reusable vehicle which is capable of achieving earth orbit while carrying some useful payload and then returning.

RLV Concepts. Three companies are currently participating in Phase I of the NASA-industry RLV program, the concept definition and technology development phase. One of these three will be selected to continue developing its RLV concept in Phase II of the program, the demonstration phase. NASA has scheduled source selection to be complete by July 1996.[1] The winner of

this source selection will develop an advanced technology demonstration vehicle, the X-33, which will be used to conduct flight tests in 1999. The focus of this second phase will be to demonstrate aircraft-like operations and provide enough evidence to support a decision on whether or not to proceed with the next phase in the year 2000. Phase III of the RLV program would include commercial development and RLV operations.[2] The decision to enter Phase III will be a complex one. It will depend on Phase II results as well as many other contextual factors bearing on decision makers at the turn of the century. In keeping with the recommendations of NASA's *Access to Space Study,* all phases of the RLV program are to be "driven by efficient operations rather than attainment of maximum performance levels."[3]

All the RLV concepts are currently focused on satisfying the requirement to deliver and retrieve cargo from the International Space Station, Alpha (ISSA). This, perhaps artificially, drives a certain payload requirement (see table 1).[4] All three concepts use cryogenic propellants, liquid oxygen and liquid hydrogen, to achieve high specific impulse.[5] Other common attributes are based on objectives of the RLV program, such as the mission life and maintenance requirements.[6] The required thrust-to-weight ratio (F/W), specific impulse (I_{sp}), and mass fraction are based on current estimates and analysis.[7] Current cost estimates are based on paper studies. The estimates vary widely and are affected by the size of the RLV, the number built, whether or not they are certified to fly over land, the basing scheme, other aspects of the concept of operations, and the acquisition strategy, to name just a few of the factors involved.[8] For example, a smaller, lighter, and less capable (with respect to payload) RLV would presumably prove cheaper to build and face less technical risk in development.[9]

Where the three RLV concepts diverge is in their propulsion systems and takeoff and landing concepts. Lockheed Advanced Development Company's RLV would be a lifting body using linear aerospike rocket engines as opposed to more traditional rocket engines with bell-shaped nozzles.[10] The vehicle would takeoff vertically and land horizontally (VTHL). McDonnell Douglas Aerospace's RLV would be a conical reentry body using traditional bell-shaped nozzle rocket engines. The vehicle would takeoff vertically and land vertically (VTVL). Rockwell Space System Divisions RLV would be a winged body using traditional bell-shaped nozzle engines.[11] Like the Lockheed concept, Rockwell's is a VTHL vehicle (see fig. 1 for an artist's concept of all three vehicles).

Black Horse. The Black Horse TAV concept was identified by Air University's *SPACECAST 2020* as the most promising spacelift idea evaluated by the team.[12] The Black Horse is included here for comparison because it continues to be of interest to military spaceplane advocates and provides an interesting contrast to the concepts being explored under the NASA-led RLV program. However, this is comparing apples and oranges to a great extent. The Black Horse does not come close to achieving the RLV payload capability (see table 1).[13] Also, some analysts have doubts about its technical feasibility.[14] Even if Black Horse were technically feasible, the

Table 1

Attributes of Proposed RLV Concepts and One Popular TAV Concept

Vehicle	Payload	Propulsion	Mass Fraction	Takeoff & Landing Concept	Cross-range Capability	Turn-around Time	Mission Life	Non-recurring Costs	Recurring Costs
Lockheed Advanced Development Company RLV	25K lbs. to ISSA orbit (50x244 NM x51.6 deg.) 40K lbs. to 100 NM circular orbit	LOX/LH_2 Linear Aero-spike engines F/W = 75 I_{sp} = 440 (vacuum I_{sp})	0.10 – 0.11	VTHL Lifting Body Runway requirements for landing (8K feet)	500–600 NM	Nominal: 7 days Contingency: 2 1/2 days	100 (Depot maintenance after 20 missions)	$5 – 20B	Annual costs $0.5 – 1.5B (4 vehicles) $1K/lb.
McDonnell Douglas Aerospace RLV	25K lbs. to ISSA orbit 40 K lbs. to 100 NM circular orbit	LOX/LH_2 (tri-prop opt.) Bell nozzle rocket engine F/W = 75 I_{sp} = 440 (vacuum I_{sp})	0.10 – 0.11	VTVL Conic reentry body Propulsive landing on 150x150 foot grate	11–12K NM	1–2 days	100 (Depot maintenance after 20 missions)	$5 – 20B	Annual costs $0.50 – 1.5B (4 vehicles) $1K/lb.
Rockwell Space Systems Division RLV	25K lbs. to ISSA orbit 40 K lbs. to 100 NM circular orbit	LOX/LH_2 (tri-prop opt.) Bell nozzle rocket engine F/W = 75 I_{sp} = 440 (vacuum I_{sp})	0.10 – 0.11	VTHL Winged body Runway requirements for landing (10K feet) Erect for takeoff	Nominal: 800 NM Contingency: 1100 NM (with TPS degradation)	Nominal: 7 days Contingency: 3 1/2 days	100 (Depot maintenance after 20 missions)	$5 – 20B	Annual costs $0.50 – 1.5B (4 vehicles) $1K/lb.
Black Horse TAV	1K lbs. to 100 NM circular orbit (4x5x6 feet)	Jet fuel & H_2O_2 Rocket engine I_{sp} = 323–35	0.05 in theory, but aerial refuel allows 0.08 mass fraction	HTHL Runway req. for takeoff and landing (3,150 feet)	1800 NM+	12 hours – 1 day	Unknown	$700M "X" program cost = $150M	$260K/sortie Annual costs $100M (8 vehicles) $1K/lb.

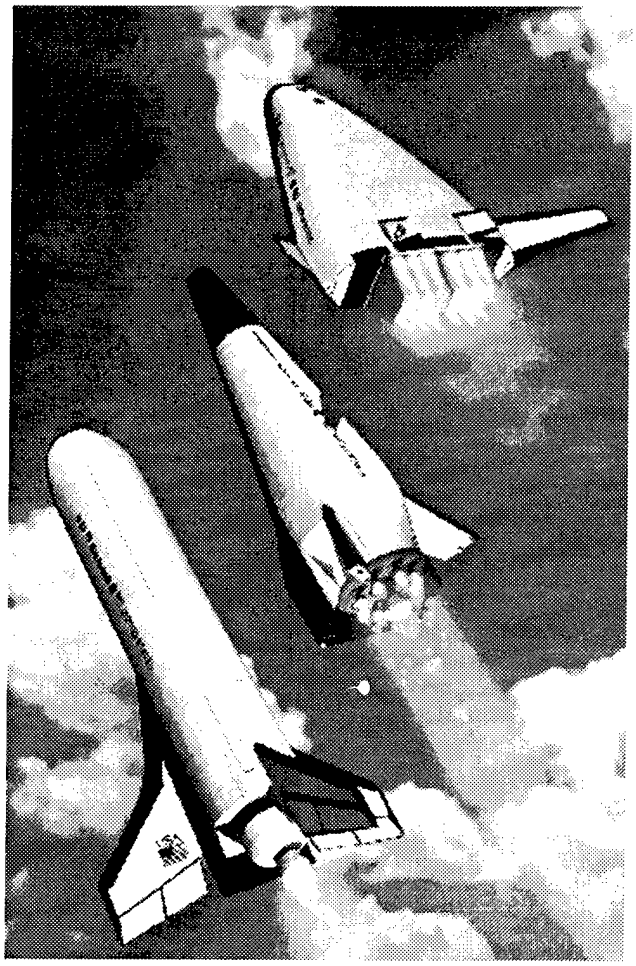

Figure 1. Current RLV Concepts

market for small payload launchers is highly competitive and includes the most operationally responsive of all expendable vehicles.[15] This would likely limit Black Horse's utility to only military missions, and perhaps just a subset of those.

Discussion of Requirements

The officially stated requirements for the RLV concepts currently being proposed do not include conducting military operations such as reconnaissance and strike (in and from space). As discussed earlier, there is growing support for developing a system that is capable of accomplishing these missions. It will be a great challenge to identify a system that can meet these military requirements, does not require a great increase in the military space budget, and also satisfies civil (non-DOD government) and commercial needs.

Payload. The payload capability required of an RLV is a very important attribute. Determining the desired payload weight and size capability based on anticipated requirements for delivering and retrieving satellites and other cargo to and from orbit, flying reconnaissance payloads to space and back, and delivering weapons on the other side of the earth is not enough. Determining the desired payload weight and size must also be tempered by the technical risks, monetary costs, and operational costs which might be incurred as a result of establishing the payload requirement. The payload requirement drives the vehicle's physical size, engine performance requirements, development cost, and other attributes. There is general, although not complete, consensus that a smaller RLV than currently conceived by NASA may be more feasible. An argument for the smaller vehicle can be made based on three factors.[16]

First, the National Research Council's 1995 assessment of the RLV Technology Development and Test Program indicated that scaleability of structures from the X-33 test vehicle to a full-scale RLV is an area of uncertainty.[17] The report also concluded that "an increase of 30 percent or more" in current rocket engine performance will be required for the full-scale RLV.[18] The X-33 engine will not satisfy full-scale RLV performance requirements, so development of a new engine will be required. The report estimates it will take a decade to develop.[19] The report does not comment on the feasibility of developing a full-scale RLV but identifies the necessary engine development as a "difficult challenge."[20] These conclusions suggest that developing an RLV closer in size to the X-33 would minimize potential scaleability problems and reduce the requirement for increased engine performance. The result would be less technical risk.

Second, incurring less technical risk may also directly contribute to incurring less financial risk. If RLV development can avoid the need to develop engines with thrust-to-weight ratios of more than 75, then nonrecurring costs may be reduced. Cost is an important consideration for both government and commercial funding. Reducing the cost of access to space, not performance, is the primary driver for the RLV program.

Third, the greatest demand for launch services is not in the area of delivering 40,000 pound payloads to low earth orbit (LEO). Recent forecasts show the greatest demand to be in the medium and small payload class, not more than 20,000 pounds to LEO, and less than 10,000 pounds to geosynchronous transfer orbit (GTO).[21] These forecasts may indicate that sizing an RLV to compete in this market is more likely to result in a successful commercial development. Developing a less expensive vehicle that can satisfy commercial requirements as well as the majority of government requirements has the greatest potential for economic development. Of course, a larger RLV could deliver smaller payloads, perhaps more than one at a time, but it is not at all clear that using the larger RLV would be more efficient. The Titan IIIC, a large spacelifter originally designed to support launches of the Dyna-Soar spaceplane, never quite caught on as a commercial vehicle. The Ariane 5 was originally designed to launch the Europeans'

Hermes spaceplane which has since been canceled.[22] It remains to be seen if the heavy-lift Ariane 5 can become a commercial success without government assistance.[23]

An argument against developing a smaller vehicle can be made based on the fact that it would not satisfy all the government's requirements. For instance, it might not be able to deliver the necessary cargo loads to the space station or launch the largest national security payloads. Some suggest that even commercial payload size is on the increase.[24] This deficiency could be addressed in several ways. First, a large RLV could be developed after the smaller version, allowing more time for technology maturation and the development of an experience base with the smaller RLVs. In the interim, the large government payloads could be delivered using existing systems or the heavy-lift version of DOD's EELV projected to be available in 2005.[25] Second, the large payloads could, in theory, be made smaller, by taking advantage of miniaturization or by assembling modular components in orbit. Making payloads smaller may not be a panacea, especially for space station loads, but there is some evidence that the DOD is moving in this direction.[26] Third, a technique referred to as a pop-up maneuver may be used to deliver large payloads with a smaller RLV. This would entail flying the RLV on a suborbital trajectory to deploy larger payloads into LEO than it would be possible to deploy if the RLV itself had to achieve orbit.[27] The pop-up maneuver requires the physical dimensions of the payload bay in the smaller RLV to be sized to accommodate the largest payloads the vehicle is planned to fly. It also forces the RLV to land downrange and be flown back to the primary operating base.

Cargo area dimensions for an RLV are under study, and recommendations vary considerably. NASA's *Access to Space Study* considered payload bay lengths of 30 and 45 feet—large enough for space station cargo but still too small for some national security needs.[28] The USAF's Phillips Lab has proposed a 25-foot-long payload bay to satisfy military requirements.[29] One RLV competitor, Rockwell, believes a 45-foot payload bay is needed even to accommodate "future generations of commercial satellites and their upper stages."[30]

Propulsion and Mass Fraction. Propulsion and mass fraction are important attributes of an RLV but are not stated as desired attributes here. The appropriate figures would result from design of an RLV to meet other requirements.

Takeoff and Landing Concept. An RLV's methods of takeoff and landing are significant to the extent that they affect its operations. Obviously, the need for a runway limits basing and delivery access options. The VTHL vehicles will also require some means for erection prior to launch. On the other hand, even a VTVL vehicle will require some unique basing support, such as a 150-foot-square grate.[31] Both approaches require cryogenic fuel facilities which are not typically available at most airfields. Perhaps more important than whether an RLV lands vertically or horizontally is the overall ease and simplicity of operations achieved through its design.

Cross-range Capability. The term *cross-range capability*, as used here, refers to the ability of an RLV to maneuver within the atmosphere upon its return from space. This does not include the ability of an RLV to change its orbital path while in space.[32] The ability of an RLV to maneuver within the atmosphere can be a significant advantage during contingencies requiring an abort while ascending or a change in landing location while returning from a mission. This capability could also prove very useful in military applications. For ascent contingency purposes, 600 nautical miles (NM) is adequate.[33] If the vehicle must land at the same base from which it took off after one revolution around the earth, then a cross range on the order of 1,100–1,200 NM is required.[34] The cross-range capability requirement for certain military missions could potentially be higher.

Turnaround Time. For commercial and civilian applications, this attribute is primarily an efficiency question. It will contribute to determining how many RLVs are needed and the nature of launch base facilities. For military missions, this attribute is not only related to efficiency but effectiveness as well. Reconnaissance and strike missions in particular could be facilitated by shorter turnaround times. Related to turnaround time is the issue of responsiveness, how long it takes to prepare an RLV for launch. Again, military missions are likely to demand quicker response times.

Mission Life. This attribute is closely related to costs. Given the current uncertain state of RLV technology, it is hard to predict what a reasonable mission life would be, so the figure of 100 has been established. Some think a 500 mission life is a reasonable expectation.[35] The frequency of required depot maintenance is also difficult to anticipate.[36]

Other Attributes. There are several other attributes not yet addressed which can significantly affect RLV operations, such as the ability to operate in adverse weather conditions and crew size. Today's spacelift vehicles are severely constrained by weather, from lightning potential, to winds at altitude, to winds on the surface.[37] Delays due to weather can add to the cost of operations and dramatically decrease responsiveness. A truly operational RLV, especially one which will conduct military missions, should be able to operate in all but the most extreme weather conditions. A truly operational RLV should also require smaller operations crews than are required by current systems. Today, thousands of people are employed in STS launch base operations at the Kennedy Space Center. Unmanned, expendable launch vehicle operations at Cape Canaveral Air Force Station require hundreds of people to launch a vehicle. These figures should be well under 100 for an operational RLV.[38] Finally, all payloads should use standard containers and interfaces to facilitate operations efficiency and responsiveness.[39]

Desired Attributes for a Notional RLV

A review of current concepts under study and development in support of the RLV program provides reasonable bounds for requirements or desired attributes for a notional RLV which could be used to support military

missions. At the same time, one of the assumptions underlying this study is continued fiscal constraint. This assumption is the basis for a desire to maximize dual use or triple use (i.e., military, civil governmental, and commercial use) of an operational RLV to the greatest extent practical. If more user requirements can be satisfied, especially those of commercial operators, it is more likely that funding will be available and that economies of scale can be achieved. Of course, trying to satisfy too many requirements with one vehicle could lead to failure. Defense procurement history is filled with programs that attempted to satisfy so many users that they failed to stay within budget, stay on schedule, or deliver the desired operational capability. With this caution in mind, the attributes of a notional RLV to be used as the basis for analysis are described below.

The notional RLV should be able to deliver 20,000 pounds to a circular LEO with an altitude of 100 NM (see table 2). This payload weight capability should also allow the vehicle to deliver commercial communications satellite-sized payloads to GTO, carry reconnaissance payloads on orbital or suborbital missions, and deliver significantly more weapons payload than today's F-16 and F-117 fighter aircraft or as much as an SS-18 heavy intercontinental ballistic missile (ICBM).[40] Its propulsion system's attributes are not described or stated as requirements, but based on current RLV concepts the assumption is that cryogenic rocket engines will be used. The method of takeoff or landing is also not specified. To provide a basis for analysis, it will be assumed that any RLV operating base will need no longer than a 10,000-foot runway. If a VTVL vehicle is pursued, this requirement might still exist in practice if it is necessary or desirable to supply an operating base rapidly using large transport aircraft. In any case, this assumption should not constrain choices of operating bases too severely. An RLV used for military applications must have shorter turnaround and response times than what might be necessary or desired for commercial and civil applications, but a nominal one-day turnaround, 12 hours for contingencies, and a six-hour response time do not seem unreasonable based on current concepts. Standard payload containers and interfaces would be used for all missions. Finally, mission life and costs are essentially accepted from the current concepts with one exception. Given the choice of an RLV with less payload capability, the cost figures are estimated to be in the lower end of the range established for a full-scale RLV.

Conclusion

The concepts being proposed for a full-scale RLV under the NASA-industry RLV program are driven by requirements which may not be completely compatible with requirements for a military RLV. The large, full-scale RLV may not target the spacelift market in the most economically viable way. Given the potential to reduce technical risk, save money, and more effectively

Table 2

Summary of Attributes of a Notional RLV

Attribute	Value
Payload Size & Weight	20K lbs. to 100 NM circular orbit (due east) 30-foot-long cargo area
Propulsion	As necessary (LOX/LH_2 propellant rocket engines based on current concepts)
Mode of Takeoff & Landing	As necessary (assume 10K foot airfield required at any RLV base)
Required Runway Length	10K feet maximum (if necessary at all)
Cross-range Capability	1,100 NM minimum
Turnaround Time	1-day nominal, 12-hour contingency (6-hour response)
Mission Life	100 minimum Depot maintenance after 20+ missions
Development Cost	$4–13B
Cost Per Mission	Annual Costs: $0.50B for 4 RLV squadron <$1K/lb.

target the vast majority of user requirements, these attributes for a notional RLV can serve as a basis for CONOPS development and further analysis.

Notes

1. "Latest News, Official Announcements," Marshall Space Flight Center, Huntsville, Ala., n.p., on-line, Internet, 19 February 1996, available from ftp://rlv.msfc.nasa.gov/RLV_HTMLs/RLVNews.html.

2. "A Draft Cooperative Agreement Notice, X-33 Phase II: Design and Demonstration," Marshall Space Flight Center, Huntsville, Ala., on-line, Internet, 14 December 1995, available from http://procure.msfc.nasa.gov/pub/ solicit/can_8_3/, A-2–A-3.

3. Office of Space Systems Development, NASA headquarters, *Access to Space Study*, January 1994, 61, 69.

4. The data in table 1 came from a number of sources. Data on RLV payload capability, propulsion, mission life, and costs came from the following documents: Report of the Moorman Study, *Space Launch Modernization Plan*, 5 May 1994; National Research Council, *Reusable Launch Vehicle Technology Development and Test Program* (Washington, D.C.: National Academy Press, 1995); "Executive Review, RLV Technology Program," NASA headquarters, 24 May 1995, n.p., on-line, Internet, available from http://rlv.msfc.nasa.gov/RLV_HTMLs/LIBGen.html. Competing contractors' cost estimates are at the lower end of the spectrum but are not cited as they are proprietary and may also prove to be optimistic. The cost figures also ignore what the unit production costs might be after technology development. Data on RLV takeoff and landing methods, operations base requirements, cross-range capabilities, and turnaround times came from the following telephone interviews: Mike Pitman, Rockwell RLV/X-33 systems engineer, telephone interviews with author, 21 and 26 February 1996; David Urie, former Lockheed RLV/X-33 program manager, telephone interview with author, 22 February 1996; Paul Klevatt, McDonnell Douglas RLV/X-33 program manager, telephone interview with author, 20 February 1996. Data on the

Black Horse TAV came from Robert M. Zubrin and Mitchell Burnside Clapp, "Black Horse: Winging It to Orbit," *Ad Astra* 7, no. 2 (March/April 1995): 40–43; "Space Lift: Suborbital, Earth to Orbit, and on Orbit," *Airpower Journal* 9, no. 2 (Summer 1995): 42–64; and Capt Mitchell B. Clapp, USAF Phillips Laboratory, telephone interview with author, 26 February 1996.

5. George P. Sutton, *Rocket Propulsion Elements, An Introduction to the Engineering of Rockets* (New York: John Wiley & Sons, 1986), 21–22. Specific impulse, I_{sp} or I_s, is defined as the total impulse per unit weight of propellant. Total impulse, I_t, is the thrust force, F (which can vary with time), integrated over the burning time t. According to Sutton, I_{sp} has "units of newton-second^3/kilogram-meter. Since a newton is defined as that force which gives a mass of 1 kilogram an acceleration of 1 meter/second^2, the units of I_{sp} can be expressed simply in seconds. However, it is really a thrust per unit weight flow."

6. "Executive Review, RLV Technology Program," n.p.

7. National Research Council, *Reusable Launch Vehicle Technology Development and Test Program* (Washington, D.C.: National Academy Press, 1995), 1–8, 21, 73. Mass fraction, also known as mass ratio or MR, is defined to be the final mass of a vehicle (after propellants are consumed) divided by the initial mass (before the propellants are consumed); and Sutton, 23.

8. The potential cost impact of overland flight certification was highlighted by Paul Klevatt, McDonnell Douglas's RLV/X-33 program manager during a telephone interview with author, 20 February 1996. The importance of this issue was echoed by Dennis Smith, Marshall Space Flight Center, RLV program assistant for technology, telephone interview with author, 23 February 1996.

9. There is not complete consensus on this issue, and it will be addressed later.

10. Sutton, 63. The linear aerospike engine is a class of plug nozzle engine. A plug nozzle engine has a center body and an annular chamber, unlike the traditional bell-shaped or contour nozzle common on today's expendable rockets and STS. An aerospike nozzle is a plug nozzle where low-velocity gases (e.g., from a separate gas source) are injected in the center and replace the center body. This allows a very short nozzle hardware configuration, which is desirable for a compact vehicle design.

11. Rick Bachtel, RLV program manager, Marshall Space Flight Center, telephone interview with author, 22 March 1996. Both the MDA and the RSSD concepts will most likely use engines derived from the space shuttle main engine or the Russian RD-0120.

12. "Spacelift, Suborbital, Earth to Orbit, and on Orbit," 42–64.

13. To be fair to the Black Horse advocates on the *SPACECAST 2020* team, they did not intend to suggest great payload capability for the Black Horse. Their concept included revolutionary reductions in satellite size and weight and a greater focus on missions other than delivering payload to orbit.

14. Analysis conducted by the Aerospace Corporation and discussed at the 15 February 1996 meeting of the USAF's Military Space Plane Applications Working Group in Colorado Springs, Colo., indicates the Black Horse as described by the *SPACECAST 2020* group is not feasible. With a change from aluminum to composite material structure and a significant increase in size, the vehicle might be able to achieve orbit, but just barely. Phillips Lab's Black Horse experts are in the process of rebutting this Aerospace Corporation analysis.

15. Assistant Secretary of Defense (Economic Security), Department of Defense, *Industrial Assessment for Space Launch Vehicles*, January 1995, ES-4 and ES-12–ES-13.

16. The belief that a smaller vehicle is more feasible was the consensus of participants at a meeting of the Military Space Plane Applications Working Group held in Colorado Springs, Colo., on 15 February 1996. The participants included NASA personnel, one of whom had worked on the agency's *Access to Space Study* and claimed the analysis behind this study supported the conclusion that developing smaller RLVs involve less technical risk. This perspective is also shared by Dr. Len Worlund, director of technology for the RLV program at Marshall Space Flight Center, although he was also quick to point out that a smaller vehicle will not necessarily meet the requirements of all the users, such as NASA. Urie, recently retired RLV/X-33 program manager for Lockheed Advanced Development Company, telephone interview with author, 22 February 1996, representing a contrary view, suggested a smaller vehicle size was actually less feasible than the full-scale RLV envisioned by NASA. Like

Dr. Worlund, he was also quick to point out the fact that a smaller vehicle would not meet all user requirements.

17. National Research Council, 3.

18. Ibid., 8.

19. Ibid., 73.

20. Ibid.

21. Assistant Secretary of Defense (Economic Security), II–2. Earlier studies reached a similar conclusion. For example, see National Research Council, *From Earth to Orbit, An Assessment of Transportation Options* (Washington, D.C.: National Academy Press, 1992), 4.

22. "French Launcher Design: Evolved Ariane," *Military Space* 13, no. 5 (4 March 1996): 3–5.

23. The first two scheduled Ariane 5 launches will carry European Space Agency, not commercial, payloads. Craig Covault, "Cluster to Inaugurate Ariane 5 Flights," *Aviation Week & Space Technology* 144, no. 13 (25 March 1996): 48–50; and Craig Covault, "Reentry Flight Test Set for Second Ariane 5," *Aviation Week & Space Technology* 144, no. 13 (25 March 1996): 51–53.

24. "News Briefs, Satellite Launch Review," *Space News* 7, no. 10 (11–17 March 1996): 17. According to the Arianespace consortium, the average weight of a communications satellite will increase from the current 2,400 kilogram to 3,200 kilogram within the next four years then level off after that. This average does not include the satellite constellations for mobile communications. These weigh less than 1,000 kilogram each.

25. Assistant Secretary of Defense (Economic Security), IV–3.

26. Ibid., I–12.

27. Lt Col Jess Sponable, briefing to Military Space Plane Applications Working Group, Colorado Springs, Colo., 15 February 1996. The pop-up maneuver is essentially a nonoptimum staging maneuver in which the payload, with an appropriate upper stage, is deployed only a few thousand feet short of orbit. This maneuver can significantly increase the payload capability to orbit (or into an intercontinental ballistic trajectory).

28. Office of Space Systems Development, NASA headquarters, 56.

29. Lt Col Jess Sponable, briefing to Military Space Plane Applications Working Group, 15 February 1996.

30. Bruce A. Smith, "Rockwell Completes Design of Key X-33 Components," *Aviation Week & Space Technology* 144, no. 13 (25 March 1996): 56–57.

31. Maj Michael A. Rampino, personal observations during DC-XA flight test number nine, White Sands Missile Range, N.Mex., 18 May 1996. Based on the 18 May 1996 DC-XA flight test, this requirement may change. During this test, McDonnell Douglas used the grate and trench system for the first time with poor results. Instead of relieving thermal stress on the base on the vehicle, it actually focused the DC-XA's exhaust flame back up toward the rocket causing a fire.

32. An RLV's ability maneuver in space is a function of its propulsion system and available propellant. To some extent, an RLV may be able to trade payload weight carried for fuel increasing its ability to change its orbital path. However, given the mass fractions required of an RLV, trading all the payload capacity may still translate into very little out-of-plane maneuverability.

33. Dr. Len Worlund, RLV program technology director, telephone interview with author, 22 February 1996.

34. Wiley J. Larson and James R. Wertz, eds., *Space Mission Analysis and Design* (Torrance, Calif.: Dordrecht, 1992), 135–36 (equation 6-10). The greater cross-range requirement necessary to support landing at the base of origin after one revolution is driven by the fact that the earth will have rotated some 22.5 degrees by the time the RLV completes one 90-minute orbit. After circling the earth once, the RLV will find its orbital path is west of where it started.

$P = 4(360^{\circ} - \Delta L)$, where P is the orbital period, and

ΔL is the change in longitude that the satellite goes through between successive ascending nodes in degrees.

For this example, $90 = 4(360^{\circ} - \Delta L)$, and $\Delta L = 337.5$.

35. David Urie, former Lockheed Advanced Development Company RLV/X-33 program manager, telephone interview with author, 22 February 1996.

36. Joseph C. Anselmo, "NASA Confident of Shuttle Backups," *Aviation Week & Space Technology* 144, no. 15 (8 April 1996): 54. Drawing on analogies with today's space shuttles would not be helpful. The orbiter with the most flights, *Discovery*, has flown only 21 times. One could also assert that depot-level maintenance is required after every flight. If this kind of performance is repeated by RLVs, there is no hope for achieving the necessary efficiencies.

37. For insight into how weather affects current launch operations, see J. T. Madura "Weather Impacts on Space Operations," July 1992 (Air University Library number M-U 44059, no. 92-02) and 30th and 45th Space Wing, "Spacelift Concept of Employment," draft, 1 October 1994.

38. Urie. According to Urie, Lockheed plans on an RLV crew size between 50 and 60 people, with a total launch organization of 150 people, including administrative and logistics support personnel. NASA's Cooperative Agreement Notice for the X-33 Phase II requires demonstration of "at least three X-33 landing-to-reflight turnarounds with a ground crew (touch labor) of less than or equal to 50 personnel." "A Draft Cooperative Agreement Notice," B-11.

39. Smith, 57. Rockwell plans on this type of arrangement for their RLV concept. There is a reflection of a broader trend in the space industry to adopt common standards. In the space launch industry, DOD is funding an effort to develop standards to benefit the defense, civil, and commercial sectors. See also Jennifer Heronema, "Space Industry Officials Advocate Adopting Standards," *Space News* 7, no. 8 (26 February–3 March 1996): 10.

40. Paul Jackson, ed., *Jane's All the World's Aircraft* (London: Jane's Information Group Limited, 1995), 567–76. A nominal weapons load for an F-16 consists of six 500-pound or two 2,000-pound bombs in addition to external fuel tanks and air-to-air missiles. The greatest practical bomb load for the F-16 consists of 12 500-pound bombs or four 2,000-pound bombs, assuming no external fuel tanks are carried. The F-117 can carry two 2,000-pound bombs. The former Soviet Union's SS-18, the ICBM with the greatest throw weight, could deliver 16,700 pounds. Max Walmer, *An Illustrated Guide to Strategic Weapons* (New York: Prentice Hall Press, 1988), 12. These figures obviously do not account for enhanced weapons effects due to the method of delivery.

Chapter 3

Concepts of Operations

Introduction

This section presents an outline of two concepts of operations. The first concept, CONOPS A, is intended to be representative of military space plane advocates' visions. It uses the notional RLV described in table 2. CONOPS A makes the fullest military use of the roughly one-half scale RLV to accomplish not only traditional spacelift missions but also the additional missions of returning payloads from orbit, transspace operations, reconnaissance, and strike (in and from space). The second concept, CONOPS B, is intended to represent a logical extension of the current RLV programs' goals. It is based on the full-scale vehicle concepts currently being proposed under the RLV program (see table 1). CONOPS B also makes expanded use of RLVs. The capabilities of each RLV used for analysis are summarized in table 3.[1]

Table 3

CONOPS A and B RLV Capabilities

RLV	Fleet Size	Turnaround time (hours)	Payload	Sorties/day	20K lb. weapons/day
CONOPS A	6	Nominal: 24 Contingency: 12 Response: 6	20K lbs. to LEO	12	96
CONOPS B	4	Nominal: 48 Contingency: 24 Response: 12	40K lbs. to LEO	4	64

New systems, weapons, and technologies are usually fielded without the ultimate utility or best application (CONOPS) having been elaborated—the RLV may show its greatest application to have been unanticipated. An RLV may have to be built and operated for some time before its greatest utility is appreciated or the best methods of employment are discovered.[2] In spite of this reality, describing a CONOPS for RLVs at this early stage is vital. Without defining how an RLV force is to be fielded, organized, and operated, its development is bound to be unguided by practical considerations and its utility is guaranteed to be limited.

Constraints and Assumptions. Each concept of operations is intended to conform to the same fiscal environment—they both live within the same budget. Due to this constraint, and as a result of cost estimates presented earlier, the two concepts of operations have different numbers of RLVs available. Since CONOPS A uses the half-scale RLV developed with less technical and financial risk, six are available for employment. Since CONOPS B uses the larger RLV developed with more technical and financial risk, four are available for employment. These figures are based on the development cost estimates presented earlier (see tables 1 and 2).[3]

Overview. Each concept of operations is described in terms of its mission, systems, operational environment, command and control, support, and employment. The missions of spacelift (to and from orbit), transspace operations, reconnaissance, and strike (in and from orbit) contribute to the broader military missions of space superiority, precision employment of weapons, global mobility, and achieving information dominance.[4] The systems description includes not only the RLVs but also their associated ground systems and payloads. The operational environment addresses threats and survivability issues while command and control deals with command relationships as well as authority and responsibility for the mission and the people. Support addresses the numerous activities required to conduct successful operations. Finally, the employment discussion illustrates concepts of how the systems may be used throughout the spectrum of conflict, from peace to war and back to peace.

CONOPS A

Missions. The missions of the RLV force are to conduct spacelift, transspace, reconnaissance, and strike operations. Spacelift operations include deployment, sustainment, and redeployment of on-orbit forces—earth-to-orbit, orbit-to-earth, and intraspace transportation. Transspace operations involve delivering material through space, from one point on the earth's surface to another. Reconnaissance missions are not limited to the earth's surface, but include inspection of adversary space systems as well.[5] Similarly, the strike mission may be accomplished against surface, air, or space targets. Strikes within space will likely be accomplished with directed energy, high power radio frequency (HPRF), or information weapons rather than explosive or kinetic impact weapons to minimize the chance of debris causing fratricide.[6]

In peacetime, routine launch and recovery of spacecraft and reconnaissance will be the primary occupations of RLV forces. Exercises, training missions, and system tests will also be accomplished. During contingencies, requirements for responsive launch, transspace operations, and more frequent and responsive reconnaissance are likely.[7] Contingencies may also include the need for heightened readiness to accomplish strike missions. During wartime, the full range of missions must be anticipated. Actions to achieve control of the space environment, such as reconnaissance and strike against adversary

space systems, as well as surge launch and transspace operations will be conducted.[8] RLVs may be called upon to accomplish prompt strikes against surface targets early in a conflict in an attempt to disrupt an adversary offensive.[9] Once hostilities have passed the opening stages, RLV operations would continue, complementing the capabilities of forces from other environments. For example, strikes from space may enable attacks on targets which would otherwise be beyond the reach of air, land, and sea forces. Strikes from space may also enable attacks against targets deemed too heavily defended for nonspace forces. Once hostilities have ceased, RLV forces may be called upon to conduct reconnaissance missions and provide a deterrent force so air, land, and sea forces may redeploy. RLV strike readiness could be maintained to ensure a prompt response if an adversary decided to take advantage of force redeployment and resume hostilities.

Systems. Six RLVs with the attributes described earlier are available (see tables 2 and 3). Payload capabilities include a wide range of systems all using a standard container and interface.[10] Spacecraft, reconnaissance payloads, and weapons dispensers use the same standard container to ensure simplicity and ease of RLV operations. For surface attack, weapons options include maneuverable reentry vehicles which may contain a variety of munitions and guidance systems depending on the nature of the targets to be struck.[11] For strikes within space, weapons options include directed energy, HPRF, and information munitions. In-flight vehicle operations and control may be affected remotely; however, the vehicle is capable of executing all missions based on programs loaded prior to takeoff. The ability to operate autonomously helps minimize the force's vulnerability to electronic warfare and enhances in-flight security. Communication for purposes such as in-flight operations and control and payload data transfer is available throughout the mission primarily through space-based tracking and data relay spacecraft, though line of sight communication with ground stations is possible. RLV self-defense capabilities include its ability to use maneuver and speed to avoid threats, and onboard electronic and optical countermeasure systems which can operate autonomously and through remote control. The vehicle's thermal protection system gives it some inherent passive defense against lasers. As with vehicle operations and control, in-flight payload operations and control may be affected remotely. The payload functions can also be executed based on programs loaded prior to takeoff. The two primary operating bases are located in Florida and California.[12] Four alternate bases may be used as necessary. Two of the alternate bases are located on the coasts—one each on the East and West Coasts. The other two alternate bases are located in the US interior. The alternate bases may be used in the event of contingencies such as those related to system malfunction, extremely severe weather, or threats to primary base physical security. RLV units and personnel also have the capability to establish a contingency base at virtually any airfield in the world with a runway length capable of accommodating large jet-powered aircraft. Other space systems necessary for RLV operations besides the

tracking and data relay satellites already mentioned include communications satellites, warning satellites, and space surveillance systems.

Operational Environment. The operational environment of the RLV currently contains few direct threats. However, the proliferation of technology, particularly rocket, spacecraft, and directed energy technology, combined with the increasing importance of space operations to warfighting success indicates that more threats are likely to develop. It would be tempting to follow Giulio Douhet's example from the 1920s and predict there will be no way to defend against an RLV attack, but this is not likely to be the case.[13] The world's leading spacefaring nations, America and the former Soviet Union, have already demonstrated the capability to attack spacecraft using ground-based and air-launched kinetic impact weapons as well as co-orbital kinetic impact systems. Lasers and other directed energy devices may also present threats in the RLVs operational environment.[14] When in flight, the RLV's onboard defensive systems and inherent maneuverability and speed make it difficult for adversary weapon systems to prevent mission accomplishment. The fact that an adversary has to detect the RLV's launch, predict its orbit, pass that information on to its defense force, and then execute an anti-RLV mission would require a high degree of technological sophistication and operational capability. Striking an RLV will be more complicated than a typical antisatellite (ASAT) mission where the spacecraft's orbit is well established, predictable, and less likely to be altered. However, even if an RLV in flight poses a difficult target for an adversary, its associated command and control centers, communications links, and bases are very vulnerable to enemy attack. This vulnerability drives the need for warning and other intelligence support, an autonomous operations capability, active and passive operating base defenses, and redundant systems. Secure, antijam, low-probability-of-intercept, communications connectivity provides some measure of protection for in-flight vehicle and payload operations and control when autonomy is not acceptable.[15] Assuming vehicle autonomy and security measures for necessary communication links are achieved, the system's greatest vulnerability will be at the operating base. The existence of alternate bases and the capability to establish contingency bases mitigates this vulnerability when combined with active and passive base defense measures.

Command and Control. RLV forces are divided between military and commercial organizations. During peacetime, four of the six RLVs available are operated by a commercial organization engaged primarily in providing spacelift services. This company also provides commercial remote sensing services. The remaining RLVs are operated by the US military under the Combatant Command (COCOM) of the commander in chief, United States Space Command.[16] The military RLVs conduct very little spacelift during peacetime to avoid any real or perceived competition with the US commercial spacelift industry.[17] They primarily conduct reconnaissance while training for and exercising their strike and transspace missions.

During times of heightened tension or war, the National Command Authorities may direct mobilization of some or all of the commercial RLV fleet based on existing government-industry agreements.[18] These RLVs may then be modified as necessary to conduct military missions. This mobilization of commercial RLVs is necessary to avoid requiring commercial organizations and their employees to accept the increased risk, hardship, and discipline required of military RLV missions. In a war, RLVs used in direct military action or in support of military operations, along with their associated systems, facilities, and personnel, will likely be targeted by the enemy. When CINCSPACE is acting as the supporting CINC to a geographic CINC, RLV forces may be put under the tactical control (TACON) of the joint force commander (JFC) to ensure the most effective use of these systems in direct support of the theater campaign plan.[19] For air and surface strike missions, the joint force air component commander will normally direct the use of RLV forces.[20] CINCSPACE directs the use of RLV forces supporting the campaign for space superiority and conducting transspace missions. RLV forces may be used to help wage a campaign for space superiority by conducting strikes and reconnaissance within space, spacelift, and strikes against surface-based elements of an adversary's space force. The JFC resolves any disputes over apportionment and allocation of RLV forces.

Support. Intelligence support for RLV forces covers a broad range of requirements. Operating base threats must be assessed and threat information provided continuously. Such information will drive defense status and relocation from prime to alternate bases or deployment to a contingency base. RLV surface strike missions will require extensive intelligence support, similar to that required to accomplish precision strikes with today's air forces or missiles. Strikes in space will require extensive space surveillance support. Some space surveillance information may actually be collected by the RLV itself, but it will require support from systems or a network with broader and continuous coverage of the near-earth environment. Mission planning will require not only the information just described but very capable computer hardware and software to process planning information inputs and to generate mission programs for in-flight payload and vehicle operations. Security of operating bases is paramount. The greatest threats may come from terrorists or an adversary's special forces. In this regard, security requirements will be similar to today's requirements to protect high-value assets at DOD bases in the continental United States—except that the threats will have evolved by the year 2012. Logistics support is simplified to the greatest extent practical. Organizational-level maintenance actions at the operating bases are accomplished by military enlisted maintenance technicians organic to RLV units. The primary RLV base on the East Coast is home to RLV unit headquarters.[21]

Employment. During contingencies and war, RLV operations consist of three phases: readiness planning, mission planning, and execution. Readiness planning requires being responsive to world events and direction from higher headquarters to maintain a specified readiness posture. At the highest state

of readiness, RLVs may be maintained on alert to respond within six hours for surge spacelift, transspace, reconnaissance, or strike missions. The RLV force's ability to execute specific missions within six hours may be constrained by factors beyond the control of the RLV force. For instance, orbital dynamics may dictate an appropriate launch time for a particular spacecraft deployment, space strike, or space reconnaissance mission that falls beyond the six-hour response time—the RLV may be available, but physics will require waiting longer to execute the mission. Maintaining alert at the highest state of readiness impacts RLV availability to conduct routine missions. Mission planning is conducted once a hypothetical or actual mission tasking is received. Mission planning is conducted by the RLV unit, nominally within one hour for any mission, taking full advantage of the support outlined above. Mission planning includes payload selection and generation of mission programs to be loaded prior to takeoff, assuming the specified mission has not been previously planned and stored for later use. The execution phase of RLV operations includes final launch preparations, launch, flight operations, and recovery. Recovery is normally at the base from which the sortie generated. System malfunctions, extremely severe weather, or threats to base security may drive recovery at another base. Transspace operations may require establishment of a contingency base and operations from that location. RLV recovery is followed by immediate preparation for subsequent missions. Deployment to an alternate or contingency base may be directed by higher headquarters or the local RLV unit commander.

CONOPS B

Missions. The missions of the RLV force are to conduct spacelift, transspace, reconnaissance, and strike operations. The CONOPS B RLV force of four full-scale vehicles is commercially operated. Given the full-scale RLV's longer turnaround time relative to the notional CONOPS A RLV, its utility for reconnaissance and strike missions during contingencies and war is diminished but not eliminated. Further, its completely commercial operation complicates use of the RLV fleet in direct military actions.[22] Nevertheless, this CONOPS include strike operations for completeness and to provide a basis for subsequent analysis.

During peacetime, routine launch and recovery of spacecraft and remote sensing will be the primary occupation of the RLV fleet. During contingencies, requirements for responsive spacelift, transspace operations, and surface reconnaissance are likely. Actions to achieve control of the space environment, such as reconnaissance and strike against adversary space systems, are also likely to be required. During war, surface strike missions may be conducted. Once hostilities have ceased, RLV forces may be called upon to conduct reconnaissance missions and maintain some level of strike readiness.

Systems. Four RLVs with the attributes described earlier are available (see tables 1 and 3). Payload capabilities are similar to those described for the CONOPS A RLV in that they all use a standard container and interface, but

the weight and size of CONOPS B payloads is larger. In-flight vehicle operations, communications, self-protection systems, and payload operations are the same. The basing scheme includes the same two primary operating bases. There are no designated alternate bases, but the operators have the capability to establish a contingency operating base at virtually any airfield in the world with a runway length capable of accommodating large jet-powered aircraft.

Operational Environment. The operational environment of the RLV is much as described under CONOPS A, except it is less hostile. The apparently civilian, and thus less threatening, nature of peacetime RLV operations would minimize the provocation of hostile action against the vehicles by potential adversaries. Refraining from exercising the RLV fleet in strike operations during peacetime could help to de-emphasize any potential military applications. Exercising strike operations would obviously hurt the RLV fleet's peaceful appearance, although it would undoubtedly improve the operators' proficiency to execute the mission. Unfortunately, regardless of whether or not the RLV fleet is used for strike missions, threats from ASAT-like systems as described above for CONOPS A are still likely to exist. Further, as long as the RLV fleet is used in even indirect support of military operations (e.g., surge launch of spacecraft used to support military surface or air operations), it will be a potential target of enemy action.

Command and Control. The RLV force is owned and operated entirely by a commercial organization.[23] The company provides spacelift and remote sensing services for government and commercial customers. US government agreements with the RLV operator include a measure of military oversight and involvement to ensure the RLV force is ready and available to conduct missions in support of national security objectives in peace and in war. The systems are never operated by military personnel, but mobilization agreements allow for close military direction of activities during contingencies and war. The secretary of defense (SECDEF) may approve mobilization of the RLV fleet during contingencies and war for the purposes of conducting spacelift and transspace operations in support of national security requirements. The president must approve any use of the RLV fleet for strike missions. When mobilized, CINCSPACE exercises COCOM over RLV assets. CINCSPACE also retains operational control (OPCON) and TACON of all RLVs given the fleet's high value and few numbers.[24] When strike operations are to be conducted, military personnel must be present to provide a measure of positive control.

Support. Intelligence support to RLV forces is much the same as under CONOPS A. Logistics support requirements are less stringent due to decreased readiness required for deployment and mission accomplishment. Maintenance actions are accomplished entirely by civilian personnel. There is no requirement for military personnel to be trained and certified in maintenance or operations tasks. Military personnel simply develop tasks and oversee their execution by the commercial civilian operators. The only exception is with respect to strike missions. Military personnel working with

RLV operators must be trained and proficient in implementing positive control measures for RLV strikes. Military personnel are assigned to a detachment colocated with the RLV operator's headquarters.

Employment. During contingencies and war, RLV operations will be responsive to national security requirements. If directed by the secretary of defense, the RLV fleet will be mobilized to conduct surge spacelift and transspace operations. These operations would be conducted in the same fashion as peacetime RLV operations, but with close military coordination. SECDEF mobilization of the RLV fleet will require the civilian operators to meet contingency turnaround and response times of 24 and 12 hours, respectively. CINCSPACE will direct tasks and priorities for the fleet once mobilized. CINCSPACE, in conjunction with the supported CINC if CINCSPACE is playing a supporting role, will determine whether or not RLV strike operations are warranted and request presidential approval as appropriate. If use of the RLV fleet for strike missions is approved, measures will be taken to ensure military control of these operations.

Conclusion

This section presented an outline of two concepts of operations. The first concept, CONOPS A, attempts to make the fullest military use of the roughly half-scale notional RLV to accomplish not only traditional spacelift missions but also the additional missions of returning payloads from orbit, transspace operations, reconnaissance, and strike (in and from space). CONOPS A is intended to represent military space plane advocates' visions. The second concept, CONOPS B, based on the full-scale vehicles currently being proposed under the RLV program, also attempts to make expanded use of RLVs, but their application is inhibited by design attributes and completely commercial operation. CONOPS B is intended to represent a logical extension of the current RLV program's goals.

Notes

1. The capabilities described in this table are based on the discussion of RLV attributes in the previous chapter. CONOPS A capabilities reflect the desired RLV attributes described in table 2. CONOPS B capabilities reflect a composite of the attributes currently conceived by the three RLV program competitors. In the case of turnaround time, this table actually reflects the shortest time of any of the concepts rather than an average. Table 3 also assumes all RLVs are completely mission capable—none undergoing maintenance, lost in accidents, or lost to enemy activity. Finally, the RLVs will require some form of weapons dispenser. Based on examination of the USAF's most recently developed bomber, the Northrop-Grumman B-2 Spirit, it is estimated that eight 2,000-pound weapons may be carried on one rotary launcher assembly (RLA), and that each RLA weighs 4,000 pounds. Paul Jackson, ed., *Jane's All The World's Aircraft* (London: Jane's Information Group Limited, 1995), 614–17.

2. This sentiment is echoed in the *New World Vistas* study. "The first attempt to apply new concepts is a necessary, but not sufficient step. In military systems, the second step in the

development of a radically new concept must be determined after operational deployment. The warfighters will use the system in innovative ways not described in the manuals." USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century,* Summary Volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995), 13.

3. This is a very conservative estimate of the development cost savings possible with the smaller RLV—it could well be twice as cheap. But this conservative estimate adds more balance to the two CONOPS and may help highlight tradeoffs. One premise for the lower cost estimate on development of the smaller RLV is that a major new engine development program is likely to be required to support the full-scale RLV large payload capacity and size. The National Research Council's RLV program review supports this premise. National Research Council, *Reusable Launch Vehicle Technology Development and Test Program* (Washington, D.C.: National Academy Press, 1995).

4. The terms *space superiority, precision employment, global mobility,* and *information dominance* are used to describe four of the five USAF core competencies. They are not used to imply the USAF must own or operate RLVs for military applications, but to illustrate the connections between the capabilities and a larger mission area or strategy. For example, the ability to quickly launch national security spacecraft in response to some contingency in addition to the ability to reconnoiter and strike enemy spacecraft as necessary can provide the basis for affecting control of the space environment for friendly exploitation while denying the environment to an adversary—the essence of space superiority.

5. In the earliest days of the space age, the USAF proposed satellite interceptor project (SAINT), involved using an orbital vehicle to inspect potentially hostile spacecraft. The USAF also hoped to develop SAINT into an ASAT system. The project was canceled on 3 December 1962 for a number of reasons. It contradicted the US government's desire to emphasize the peaceful nature of its space program, and it experienced technical, conceptual, and financial difficulties. According to historian Paul Stares, by the mid-1960s ground-based systems were capable of a great deal of information gathering without the added expense and potential political problems of an orbital system. Paul B. Stares, *The Militarization of Space* (Ithaca, N.Y.: Cornell University Press, 1985), 112–17.

6. The USAF's Scientific Advisory Board's *New World Vistas* study discussed the utility of these types of weapons for space control. USAF Scientific Advisory Board, 46–47.

7. Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms*, 23 March 1994, 88. A contingency is "an emergency involving military forces caused by natural disasters, terrorists, subversives, or by required military operations. Due to the uncertainty of the situation, contingencies require plans, rapid response, and special procedures to ensure the safety and readiness of personnel, installations, and equipment."

8. At least one theorist writing about future war predicts space will be "a strategic center of gravity in any future war. Both sides will want space control." Col Jeffery R. Barnett, *Future War: An Assessment of Aerospace Campaigns in 2010* (Maxwell AFB, Ala.: Air University Press, 1996), xxv. This prediction is also made in the *New World Vistas* study. USAF Scientific Advisory Board, 11, 46, and 61.

9. Barnett, xxv. Col Barnett predicts that in 2010, if the US "chooses to oppose an invasion of an ally, it must do so during the initial stages of the attack. Failure to immediately engage the enemy could prove disastrous." While this passage may contain some hyperbole, it seems intuitively obvious that being able to strike an adversary while his offensive is unfolding can be advantageous. The ability to do this without having to deploy large forces to the theater of conflict would be even more advantageous.

10. This standard should be the same for EELV.

11. Max Walmer, *An Illustrated Guide to Strategic Weapons* (New York: Prentice Hall Press, 1988), 12. These maneuverable reentry vehicles might have a precision strike capability much like the "Precision-Guided Reentry Vehicle (PGRV)."

12. Rockwell has identified two baseline locations for RLV operations, Cape Canaveral, Florida, and Edwards AFB, California. They ruled out Vandenberg AFB, California, because of concerns about flying over environmentally sensitive areas when launching to the east. While this type of overflight restriction may be lifted by 2012, its reality today drove the choice of coastal primary operating bases in this study. If overflight restrictions are relaxed or

completely lifted in the future, then primary operating bases in the interior of the CONUS may be a better choice to decrease vulnerability. Bruce A. Smith, "Rockwell Completes Design of Key X-33 Components," *Aviation Week & Space Technology* 144, no. 13 (25 March 1996): 57. Vandenberg is included here because of the anticipation that polar orbits may be desirable for some military missions.

13. Giulio Douhet, *The Command of the Air*, trans. Dino Ferrari (1942; new imprint, Washington, D.C.: Office of Air Force History, 1983), 18–19. Douhet's words "there is no practical way to prevent the enemy from attacking us with his air force" are indicative of his belief in the offensive nature of airpower and the ineffectiveness of ground-based defense against air attack.

14. Andrew Wilson, ed., *Jane's Space Directory* (London: Jane's Information Group Limited, 1995), 162–63, and 172–73.

15. It is conceivable that complete autonomy would not be acceptable for strike missions when collateral damage or fratricide concerns are extremely high.

16. Joint Publication 0-2, *Unified Action Armed Forces*, defines COCOM as "the authority of a combatant commander to perform those functions of command over assigned forces involving organizing and employing commands and forces, assigning tasks, designating objectives, and giving authoritative direction over all aspects of military operations, joint training, and logistics necessary to accomplish the missions assigned to the command." Quoted in Armed Forces Staff College (AFSC) Publication 1, *The Joint Staff Officer's Guide 1993*, 2-20–2-21.

17. Lt Col Robert Owen, "The Airlift System," *Airpower Journal* 9, no. 3 (Fall 1995): 16–29, proposes four tenets of airlift. One of these tenets suggests the military component of the US's airlift system should only do what the civilian component can't or won't do. This tenet might well apply to spacelift, especially if there is a viable military component as described in this CONOPS.

18. A similar arrangement already exists today with the civil reserve air fleet.

19. Joint Pub 0-2 defines TACON as "the detailed and usually local direction and control of movements or maneuvers necessary to accomplish mission or assigned tasks." Quoted in AFSC Pub 1, 2-22.

20. According to Joint Pub 3-56.1, *Command and Control for Joint Air Operations*, 14 November 1994, II-2–II-3, the JFACC's responsibilities do not include space forces. However, if the JFACC role is to function as supported commander for strategic attack operations, counterair operations, theater airborne reconnaissance and surveillance, and the JFC's overall interdiction effort, as described in Joint Pub 3-56.1, then it may make sense to give the JFACC authority and responsibility for planning, coordination, allocation, and tasking of RLVs used in support of a theater campaign plan and to include RLV strikes on whatever the air tasking order evolves into by the year 2012.

21. This is obviously not a critical issue for the CONOPS, but the RLV unit headquarters would be best located where most of the activity is likely to be. With the fall of the former Soviet Union, Cape Canaveral has become the busiest launch base in the world.

22. Jacob Neufeld, *Ballistic Missiles* (Washington, D.C.: Office of Air Force History, 1990), 103, 208, 252–53. Interestingly, in 1954 the USAF considered using civilian contractor personnel to operate its first Atlas ICBMs in order attain an early "emergency operational capability" by 1958. This option, described as a "PhD-type capability," was never exercised. Instead, the Atlas achieved operational status in September 1959 only after a Strategic Air Command crew completed a successful training launch.

23. The assumption here is that the commercial organization would be an American company. If the operator were to be a multinational corporation, tasking for military missions would be more complicated. At the same time, operations by a multinational corporation could provide a measure of deterrence. Any attack on a multinational RLV might invite a response from other nations as well as the United States.

24. Joint Pub 0-2 defines OPCON as "the authority delegated to a commander to perform those functions of command over subordinate forces involving the composition of subordinate forces, the assignment of tasks, the designation of objectives, and the authoritative direction necessary to accomplish the mission." Quoted in AFSC Pub 1, 2-21–2-22.

Chapter 4

Analysis

The criteria used to analyze the concepts of operations described in this study include capability, cost, operations efficiency and effectiveness, and politics. Capability analysis includes all the required mission areas: spacelift, reconnaissance, strike, and transspace operations. Cost analysis addresses operating base, ELV augmentation, and transspace operations costs, as well as the potential for technology maturation to reduce development costs. Operations efficiency and effectiveness analysis discusses the impact of using cryogenic propellants, deployment operations, and overall system reliability. Political analysis examines the suitability of each CONOPS in both the international and domestic environments.

Capability

Each concept of operation was intended to satisfy all RLV mission requirements: spacecraft launch and recovery, reconnaissance, transspace operations, and strike (in and from space). Each CONOPS meets these requirements but, as a result of the differences in the attributes of the vehicles used in each CONOPS and the way in which they are organized, deployed, and employed, their capabilities in each mission area vary to some degree. This variation in the extent to which each CONOPS satisfies mission requirements is examined below.

Spacelift. Both CONOPS provide dramatically improved spacelift capability from a responsiveness perspective. The most responsive of today's spacelifters requires a minimum of two months from call-up to launch compared with less than a day for either RLV described here.[1] However, when considering spacelift payload capability the two RLVs are not equal. The half-scale RLV used in CONOPS A (RLV-A from here forward) may not necessarily meet all users' needs from a payload weight and size perspective. If a smaller RLV is developed, an alternative lift means might be required, such as a heavy ELV, if a particular payload can't be downsized.

At 8.5 meters (28 feet) long and 2,724 kilogram (kg)—about 6,000 pounds—unequipped, the US components of the ISSA would fit within the dimensions of RLV-A, not to mention that they will have already been deployed long before the first operational flight of an RLV.[2] However, NASA is concerned about minimizing the number of visits to the space station to avoid disrupting microgravity materials processing work. NASA also has concerns about accommodating the crew module envisioned for transporting

US astronauts to and from the station. These concerns appear to be driving a desire for the large payload capability of current RLV program concepts.[3] Another factor behind the large payload requirement is the desire to capture the large national security payloads that currently fly on the Titan IV expendable rocket in the interest of pursuing further reductions in life-cycle costs.[4] It is difficult to predict whether or not these payloads will be lighter and smaller in the future. However, if we plan on building vehicles big enough to carry the largest payloads, it is easy to predict that payload designers will take advantage of the capability.

If large national security payloads cannot, or will not, be downsized, they could be lifted on the heavy version of the DOD's EELV, predicted to be available in 2005. If large space station payloads cannot, or will not, be downsized, they could be lifted on the heavy version of EELV as well. Large Russian rockets could also be used.[5] In fact, launching into the ISSA orbit from the Baykonour cosmodrome in the former Soviet republic of Kazakstan instead of Cape Canaveral, the planned launch base for American ISSA missions, provides more than a 35-foot-per-second velocity advantage to the relatively high-inclination orbit, 51.6 degrees.[6] This higher-inclination orbit is the same as that currently used by the Russian space station *Mir*, which was launched and is resupplied out of Baykonour. Another alternative might be launching large space station payloads on the Ariane 5. The Europeans plan to develop their own manned crew transfer vehicle as part of their participation in ISSA.[7] The Ariane 5 will be able to lift 18,000 kilograms (about 39,600 pounds) to LEO, which is comparable to the payload capacity of the Titan IV.[8]

A final, but not least significant, consideration is the need to return large payloads from orbit. While the Russians or French might happily provide return from orbit services using their Soyuz capsule or crew transfer vehicle, respectively, will they be large enough for the loads coming back from the station? As stated above, they might if we plan on using these vehicles and size the return payloads from ISSA appropriately, but certainly won't if we plan to use a larger vehicle.

Reconnaissance. Some may question the need to use an RLV for reconnaissance given the US ability to perform space-based reconnaissance of the earth's surface using satellites.[9] However, there may be times when the element of surprise is desired and not likely to be obtained using existing on-orbit assets. It is conceivable that a potential adversary might have enough information about US space-based reconnaissance systems to effectively implement operations security measures and avoid detection.[10] Another motivation for using an RLV for reconnaissance might be the need for responsiveness. For a fast breaking contingency, RLVs may provide a quick response not attainable with on-orbit spacecraft, manned aircraft, or unmanned aerial vehicles (UAV). For instance, a low-orbiting remote sensing spacecraft might not have a given location on the earth's surface within its field of view until several orbits have passed. Manned aircraft and UAVs may not allow overflight of a location deep within the target country's territory.

With respect to reconnaissance within space, one might pose a similar question about the utility of RLVs. There are undoubtedly other systems which can perform space surveillance. Paul B. Stares, in *The Militarization of Space*, claims that the USAF attempted to develop a satellite inspection system (SAINT) in the earliest days of the space age.[11] It was canceled in 1962, but Stares suggests the US ability to survey space was not degraded since advances in ground-based sensors made by the mid-1960s facilitated the gathering of a great deal of data. This may be true, but on-orbit reconnaissance may allow for more detailed as well as active inspection of spacecraft in LEO. Reconnaissance of payloads in higher orbits, such as geosynchronous earth orbit (GEO) or Molniya orbits, may require reducing the reconnaissance payload weight or may have to be conducted from a greater distance. This reconnaissance capability might also support strike missions in space with prestrike target information and poststrike battle damage assessment inputs.

Strike. Accomplishing strikes using RLVs is technically feasible. However, to be militarily useful, the vehicles should be able to deliver significant weapon payloads. With respect to surface strike, it appears RLV-A can deliver as much payload as a typical modern fighter. RLV-B can deliver as much weapons payload as a B-2 Spirit stealth bomber.[12] Obviously, there are additional considerations besides payload weight when analyzing surface strike capability. Response and turnaround times have a dramatic effect on the usefulness of RLVs for surface strike missions. Both RLVs could deliver initial strikes earlier than B-2s. Due to RLV-A's quicker response time and shorter turnaround time, it compares favorably with the strike capability of a cost-equivalent number of B-2s conducting strikes over a two-day period even though RLV-A's payload capability is roughly half that of the B-2 (see table 4 and fig. 2).[13] RLV-B, on the other hand, cannot compare as favorably through this same period despite its relatively large payload capability (see table 4 and fig. 2). The B-2's strike capability exceeds that of both RLVs over a three-day period. Strike in space using RLVs is also technically feasible. Both concepts include the capability to strike adversary spacecraft. The means used and type of strike are only limited by the creative development of strike mission payloads. For instance, RLV space strikes might be accomplished in a manner which minimizes debris and affects only a specific subsystem on board the target spacecraft. Information strikes causing disruption of adversary communications and command and control, or aimed at deception, might also be conducted. Strikes against spacecraft in high earth orbits, such as GEO or Molniya orbits, may require reducing the strike payload weight or be conducted from a greater distance.

Transspace Operations. The requirement for this capability is not very well defined.[14] One might easily doubt its feasibility except that any RLV capable of recovering and returning payloads from orbit will have an inherent capability to deliver cargo from one location on the earth to another. Putting aside cost considerations for the moment, a major factor in assessing the feasibility of transspace operations is the ability to establish an RLV

Table 4

Cumulative 2,000-Pound Weapons Delivery within Three Days

Time (hours)	RLV-A (6 RLVs)	RLV-B (4 RLVs)	B-2 Spirit (10 B-2s)
6.75	48	0	0
12.75	48	64	0
20.25	96	64	0
21	96	64	160
33.75	144	64	160
38.25	144	128	160
47.25	192	128	160
60	192	128	320
60.75	240	128	320
63.75	240	192	320
72	240	192	320

operations base at the pickup and delivery points. Experience with the subscale, suborbital McDonnell Douglas Aerospace DC-X can only hint at what an operational RLV operating base might look like. The base established for DC-X (now called the DC-XA in its modified form) operations at White Sands Missile Range, New Mexico, includes propellant facilities, electrical power facilities, vehicle control systems, and connections. The propellant facilities include liquid oxygen, liquid hydrogen, gaseous helium, and gaseous

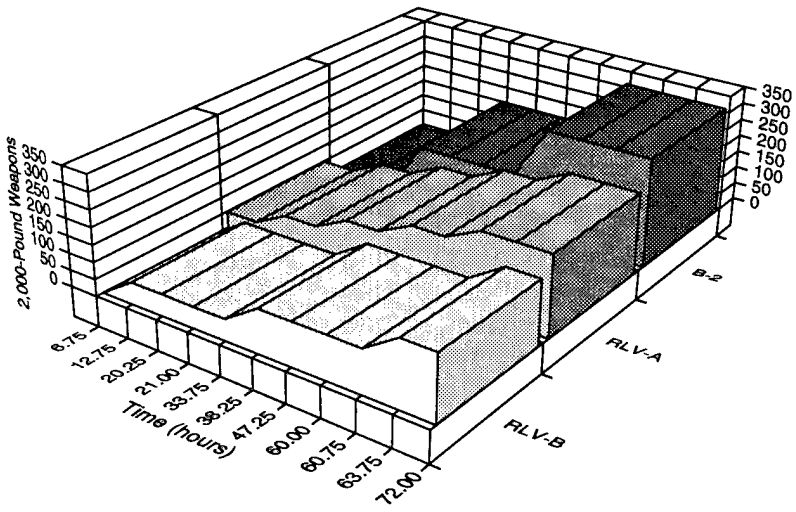

Figure 2. Cumulative 2,000-Pound Weapons Delivery within Three Days

nitrogen storage tanks, transfer lines and control systems. The vehicle control systems include ground control systems and a "real-time data system" to collect, store, and display vehicle data centrally before, during, and after flight. The real-time data system also provides a means for operator intervention, if necessary, and allows for receipt, processing, and loading of autonomous flight operations programs.[15] While an operational RLV design should include operations efficiency considerations, any RLV operating base will certainly require very large propellant facilities and associated equipment. Given that a full-scale RLV, such as RLV-B, will require about 100 times more propellant than the DC-X, the propellant facilities will not necessarily lend themselves to quick and easy transport. In this sense, RLV-A may have some advantage in that its propellant facilities would be smaller than RLV-Bs. Obviously, RLV-A also has less payload weight capability. Without a clear definition of requirements for transspace operations, it is difficult to evaluate this trade-off between the two CONOPS.

Cost

Operating Base Costs. CONOPS A is sensitive to operating base costs. CONOPS A includes two primary and four alternate bases as well the capability to establish a contingency base. CONOPS B simply has two primary bases with a capability to establish contingency bases. Launch base costs for today's fleet of expendable rockets may not be a good indicator of future RLV launch base costs given the objectives of the RLV program. This is fortuitous since today's launch bases are expensive to operate. Operating the US's largest and busiest launch base, Cape Canaveral, and its associated range costs about $160 million a year. Experience with the DC-XA is also difficult to use as a basis for estimation since the vehicle is very much smaller and less capable than an operational RLV. The DC-XA launch base also uses existing facilities and equipment at the White Sands Missile Range.[16] Nevertheless, industry sources estimate it will cost roughly $50 million to setup an RLV operating base, at a minimum. Using this figure, CONOPS A's operating base costs may be estimated at $200 million more than CONOPS B's.

ELV Augmentation. CONOPS A may also require ELV augmentation if large space station and national security payloads are not downsized. The Moorman Study reported that simply shrinking the size of the RLV payload bay from 45 to 30 feet might cost an extra $26.6 billion in ELV costs through the year 2030.[17] Employing foreign heavy lift vehicles could reduce this cost.

Transspace Operations. It is unclear that transspace operations will be economical. If one accepts the program goal of delivering payloads to orbit for $1,000 per pound, then the same estimate may be used for the cost per pound of delivering cargo from one point on the earth's surface to another using an RLV. Sending cargo internationally, say from New York to Seoul, using an express package delivery service range from about $50 per pound for a one-pound box to $5.70 per pound for a 100-pound box.[18] Sending loads by

military airlift is less expensive, but takes longer. For example, shipping a 20,000-pound load on military airlift from Dover Air Force Base, Delaware, to Ramstein Air Base, Germany, will cost $1.079 per pound and take 3.1 days, if the cargo is given the highest priority.[19] Such costs make it unlikely that RLV cargo delivery will be economically attractive. Whether or not RLV cargo delivery will be militarily useful remains to be seen.

Technology Maturation. A recurring theme in studies related to the RLV program is the idea that program costs can be reduced through technology maturation.[20] A technology development program targeted against specific high-risk areas executed before system development and acquisition can mitigate the technical and financial risks. Advancing the technology readiness of a system from "concept design" to "prototype/engineering model" prior to entering full-scale development can lower development costs by more than 40 percent.[21] Phase I of the RLV program is intended to include demonstration of the maturity level of candidate technologies.[22] The X-33 flight demonstrations at the end of Phase II represent an attempt to demonstrate technological maturity levels. However, the major recommendations of the National Research Council's recent review of RLV technology indicate a need for more vigorous development of propulsion technology.[23] There is a government-industry effort currently under way that can help address this issue. The integrated high payoff rocket propulsion technology (IHPRPT) program has goals for booster, orbit transfer, spacecraft, and tactical propulsion systems. Noteworthy booster cryogenic propulsion goals include achieving a "mean time between removal" or "mission life" of 20 for reusable systems by the year 2000, an improvement of 3 percent in I_{sp} by 2010, and an increase of 100 percent in the thrust-to-weight ratio by the year 2010.[24] Unfortunately, funding levels for this program have not increased in spite of the start of the RLV program and recommendations by high-level studies to increase funding in this area.[25] Given the critical nature of propulsion technology development to the success of the RLV program and US spacelift competitiveness in general, it is surprising IHPRPT funding has not been raised to the recommended levels.[26]

Operations Efficiency and Effectiveness

Cryogenic Propellants. Cryogenic propellants are not ideal for operations efficiency and effectiveness. A good historical basis for this assertion is the Atlas missile's short life as an ICBM. It was relegated to a spacelift only role in 1965 after being an operational ICBM for less than six years because it was not well suited to the responsive operations and reliability required of an ICBM. The extreme caution needed in fueling the missile immediately before launch kept it from ever meeting its required 15-minute reaction time. It also suffered from a host of reliability problems, many related to its propulsion system.[27] The Atlas was quickly followed by the Titan and Minuteman. The Titan ICBM, using hypergolic propellants, could stay propellant loaded since

hypergolics didn't need constant refrigeration. The Minuteman, using solid propellants, provided outstanding responsiveness and reliability.[28]

The legacy of the Atlas missile's operational life as an ICBM may provide a caution when contemplating the development of an operational RLV with a goal of high reliability and low operations costs. It may be even more relevant when considering the military use of an RLV that drives quicker turnaround and response times. Today's Atlas spacelift vehicle outfitted with a cryogenic Centaur upper stage requires cryogenic propellant loading about two hours prior to launch, well within the response time specified for either RLV-A or RLV-B.[29] During test flights in July 1995, the DC-X required a similar time line for propellant loading and was prepared to demonstrate an 11-hour turnaround time.[30] While these time lines seem to bode well for an operational RLV, there is no denying the relative complexity of cryogenic propulsion systems compared with hypergolic or solid alternatives. This complexity will make achieving RLV operations efficiency and effectiveness goals a challenge.

Deployment. The nature of cryogenic propellants also drives complexity in the RLV operating base. This complexity will challenge designers and operators faced with the problem of how to build, deploy, and operate an RLV contingency base. Ideally, such a base will be deployable by air. This is particularly true in CONOPS A, where dispersion for security and increased responsiveness for military missions is required. This contingency base capability will also be a key to transspace operations. Power and propellant systems are likely to comprise the majority of the weight and bulk required to be moved. Lessons may be learned from efforts within the USAF to develop multifunction support equipment for aircraft maintenance.[31] Being able to reduce the number of operating base support equipment pieces, as well as their size, could ease mobility requirements. It could also lead to a decrease in the number of personnel required to deploy and reduce the cost of outfitting a contingency RLV operating base. Winston Churchill once said of the Royal Air Force that "except in the air, it is the least mobile of all the armed services."[32] If the deployability of the RLV force is neglected it might suffer a similar criticism.

Reliability. Air Force Space Command's *Draft Operational Requirements Document (ORD) for the EELV*, dated 31 March 1995, defines reliability as "the ability of the spacelift system to successfully accomplish its intended mission."[33] The *ORD* defines the terms *reliability of the schedule* or *dependability* separately as "the ability of the system to consistently launch . . . when planned."[34] The Moorman Study identified three factors which affect spacelift system reliability: complexity, flight rate, and design stability.[35] After considering these factors, one can see evidence of their impact in today's spacelift systems. The Delta II, the least complex system, has the highest reliability, 100 percent over the last five years, compared to 84.2 percent and 85.7 percent for the Atlas and Titan, respectively.[36] The Delta also has the highest flight rate and the most stable design of today's expendable systems. The message for RLV development is clear: keep system complexity down,

flight rate up, and design stable. The second item, flight rate, may be achieved by capturing the largest share of the launch market practical and/or capitalizing on military applications. The third item, design stability, is aided by requiring standard payload containers and interfaces. Happily, current RLV program competitors already include a standard payload container and interfaces as a key design element.[37]

Unhappily, the National Research Council's warning about the need for vigorous propulsion system development may indicate danger ahead for RLV reliability. One of the reliability problems today's spacelifters face is their lack of performance margin.[38] A robust design approach in the RLV program could avoid this pitfall and lead to increased reliability. Rather than focusing on eliminating variation in performance, a requirement when operating a system with no performance margin, a robust design approach would minimize the effects of variation in performance. If the RLV is designed to be a high-performance system without any performance margin, then the operators will be in the same position as today's spacelift operators—reliability goals will not have been achieved. This would seem to indicate the desirability of building a system with plenty of propulsion power for its intended operations. As current RLV concepts plan on milking existing engine (SSME or RD-0120) derivatives for their last ounce of capability this will result in fielding a full-scale RLV always operating at its performance limits.[39] In this respect, RLV-A may offer some advantage, as the smaller vehicle is not likely to push propulsion performance requirements to the extent that a full-scale vehicle will.

Any potential lack of reliability is also directly related to cost in that the cost of failure is typically high in the spacelift business. The ability of an RLV to abort and land back at its base during ascent or descent may minimize the cost of failure in flight. However, any unreliability can cause delays which increase costs, although they do so less dramatically than a catastrophic in-flight failure. If an in-flight RLV failure does occur, its cost will be considerably higher than that of losing one of today's expendable spacelifters.

Finally, as highlighted by the Atlas missile's ICBM experience, reliability is a key attribute of military weapon systems. As much as cost, reliability will determine whether or not RLVs can successfully perform military missions.

Political Considerations

International. No RLV capabilities or operations described in either CONOPS A or B would violate international treaties. To some, this may be surprising. Since the dawn of the space age, the popular image of space activities has been that they are peaceful and nonmilitary. This image has been reinforced by governments, including the US government, to help guarantee the use of space for unimpeded reconnaissance. As such, there are international laws and treaties such as the Nuclear Test Ban Treaty (1963), the Outer Space Treaty (1967), and the Treaty on the Limitation of Anti-Ballistic Missile Systems (ABM) Treaty (1972), which restrict military

space activities. However, RLV forces can live within these treaties as long as they are not used to carry weapons of mass destruction, conduct ABM testing, deployment, or operations, or interfere with "national technical means (space intelligence systems)" which are being used to verify treaty provisions during peacetime.[40] This is not an exhaustive list of prohibitions, but highlights the main areas of caution for RLV military applications.

Treaties and law are not the only international political concerns related to RLVs. Developing such a dramatic new military weapon capability could appear threatening to other states. It is conceivable that other nations would resent the US's ability to strike from space or within space with little or no warning. They might respond to this threat by developing similar capabilities or by developing ASAT or anti-RLV weapons. If deployment of an RLV force were perceived as an attempt to extend American global hegemony, it could encourage other states to form alliances against the United States. Political scientist Stephen M. Walt suggests that this sort of balancing mechanism led to a favorable balance of power for the United States during the cold war. The Soviets appeared threatening to other states, which drove them into the US camp.[41] Given its completely commercial operations and more inhibited use in strike operations, CONOPS B might prove less threatening and minimize the appearance of US aggressiveness relative to CONOPS A. On the plus side, RLVs could be used for conventional strikes with the range and nearly the promptness of ICBMs, but without the nuclear baggage. Assuming the RLV force would never test or employ nuclear weapons, there should be no international concern about the start of a nuclear conflict with the launch of an RLV.

Domestic. Domestically, one concern which must be addressed is the potential US political concern associated with ASAT deployment.[42] While this would certainly not prohibit RLV development and use in spacelift, reconnaissance, and transspace operations, it might complicate development of a strike capability. If the prohibition stands, strikes in space will not be possible. Surface strikes might be allowed under the ban, but Congress would have to be convinced that the system would not operate in an ASAT role.

On the executive side of the government, NASA headquarters direction that the RLV must replace the space shuttle comes across loud and clear. While this is understandable, viewing an RLV as a shuttle replacement can be detrimental in three ways. First, it can be detrimental if it limits the designers' and planners' imagination. Second, it could be detrimental if the shuttle replacement paradigm leads simply to swapping RLVs for space shuttle orbiters, but retaining the same dated concept of operations and support facilities. Third, it could be detrimental if it forces the RLV to accommodate the same large payload sizes and weights as the space shuttle without an objective evaluation to consider if there are better options.[43]

Outside of the government, industry requires profit to survive. NASA leaders have experienced frustration in their attempt to get the private sector to fund a significant share of RLV development costs. NASA administrator Daniel Goldin recently criticized the X-33 contractors for their "lack of

courage to step up to the plate and make it happen."[44] The two-stage X-34 demonstration vehicle program has already been a casualty in the effort to encourage industry to fund reusable launch vehicle technology. The contractor team of Orbital Sciences and Rockwell International "withdrew from development of the X-34 launch vehicle after determining it would not be commercially viable."[45] The reality of industry's motivation for profit should not be surprising. It indicates that unless government is willing to fund the RLV program completely itself, the design will have to be commercially viable.

It is not likely that the government will completely fund the RLV program. The current budget environment is severely constrained and it can be expected to remain this way for the foreseeable future. Both the public and the Congress want a frugal government. The NASA budget in particular is on a downward trend. In fiscal year 1995, the programmed NASA budget for the year 2000 was $14.7 billion. The fiscal year 1997 program cut NASA's year 2000 budget down to $11.6 billion.[46] The DOD budget has suffered from the same trend and the future appears to offer little relief.[47] In short, support is not likely to be found for an expensive RLV development effort reminiscent of cold-war-era space and defense programs. RLVs will have to be developed with industry contributions. Again, commercially viability will dictate development investment and time lines.

Conclusions

Using capability, cost, operations efficiency and effectiveness, and politics as a framework for analyzing RLV concepts of operations yields several insights. First, capability analysis indicates either RLV can be used as a multirole space superiority weapon. Each CONOPS provides for spacecraft deployment, spacecraft sustainment, reconnaissance of the space realm, and strike within space as well as to the surface—key capabilities for controlling the space environment. CONOPS A may require augmentation with large ELVs given its use of the smaller RLV-A. CONOPS B may provide less flexibility and strike utility given its longer response and turnaround times. CONOPS A may have the advantage in transspace operations given the potential for RLV-A requiring smaller propellant facilities and the accompanying relaxation of mobility requirements.

Second, cost analysis indicates advantages and disadvantages for each CONOPS. CONOPS A will be sensitive to operating base costs, and may require the additional expense of maintaining access to space for heavy payloads using ELVs. It is difficult to imagine either CONOPS providing economically competitive transportation from one point on the earth's surface to another, but there may be some military utility for such missions in the distant future. CONOPS B may suffer in development costs because RLV-B is more likely to push the limits of technology, thus failing to take full

advantage of the cost reductions possible through technology maturation. Related to this observation is the final conclusion of cost analysis—funding for propulsion technology development should be increased.

Third, operations efficiency and effectiveness analysis indicates cryogenic propellants will present a challenge to designers and operators. While these propellant systems offer high specific impulse, they do not lend themselves to simplicity and ease of operations. Fortuitously, today's cryogenically propelled systems meet the required time lines for either CONOPS. Deployability will be a challenge as well. Power and propulsion systems for RLV forces will likely be physically large. Efforts to decrease the size and amount of support equipment will ease the deployment burden. Reliability is perhaps the most important attribute within the operations efficiency and effectiveness category. Conclusions drawn from the analysis indicate RLV-A may have the advantage of wider performance margins and greater reliability assuming no major propulsion technology breakthroughs are made.

Fourth, political analysis indicates a tougher environment at home than internationally for RLVs. Neither CONOPS violates international treaties or laws, although it might be in America's best interest to soften the RLV's military appearance, perhaps an advantage for CONOPS B. Domestically, the congressional ASAT ban would prohibit the use of RLVs for strike missions in space and complicate attempts to use them for strikes to the surface as well. The domestic fiscal environment poses the greatest difficulty for RLV development. NASA cannot afford to foot the entire bill for an RLV fleet, and industry will only fund what market analysis indicates is a profitable venture. The DOD is also unlikely to fund RLV development independently.

Notes

1. Report of the Moorman Study, "Space Launch Modernization Plan," 5 May 1994, 12. The minimum time required from call-up to launch for today's expendable launch vehicles is 2–4 months for Pegasus, 90 days for Titan II, 98 days for Delta II, and 180 days for Titan IV. The shuttle requires 12–33 months from call-up to launch.

2. Joel W. Powell, "Space Station Hardware," *Spaceflight* 38, no. 2 (February 1996): 54–56.

3. Rick Bachtel, RLV program manager, Marshall Space Flight Center, telephone interview with author, 22 March 1996. Bachtel estimated the crew module will weigh approximately 20,000 pounds and carry a crew of three to four astronauts.

4. Office of Space Systems Development, NASA headquarters, *Access to Space Study*, January 1994, 40 and 64–65.

5. Powell, 54. The current plans for ISSA deployment have the Russians delivering two of the largest components of ISSA, the Functional Cargo Block at 19,340 kg and the Service Module at 21,020 kg, from Baykonour cosmodrome using *Proton* rockets. Former astronaut Buzz Aldrin has suggested using the Russians' largest rocket, the 220,000-pound-to-LEO *Energia*, to lift ISSA payloads. See Darrin Guilbeau, "International Cooperation and Concerns in Space Logistics," *Air Force Journal of Logistics* 19, no. 1 (Winter 1995): 25–31. This lift capability is four times that of the Titan IV and could easily handle lifting the largest planned payloads.

6. Cape Canaveral is located at 28.5 degrees (28 degrees, 30 minutes) north latitude, while Baykonour is located at 45.9 degrees (45 degrees, 54 minutes) north latitude. Wiley J. Larson

and James R. Wertz, eds., *Space Mission Analysis and Design* (Torrance, Calif.: Dordrecht, 1992), 680. One equation used here as the basis for this estimation can be found in Roger R. Bate, Donald D. Mueller, and Jerry E. White, *Fundamentals of Astrodynamics* (New York: Dover Publications, 1971), 307 (equation 6.4-1).

V_o = 1,524 cos L_o , where V_o is the speed of a launch point on the surface of the earth, 524 ft/sec is the eastward speed of a point on the equator, and L_o is the latitude of the launch site

For launch out of Baykonour,

V_o = 1,524 cos (45.9) = 1,060.6 ft/sec

For launch out of the Cape,

V_o = 1,524 cos (28.5) = 1,339 ft/sec

In order to determine how much of the eastward velocity of the launch site actually may be used to help boost a payload, some basic trigonometry may be used.

$V_1 = V_o \cos \varnothing$, where V_1 is the velocity advantage in the direction of the launch azimuth gained from the rotation of the earth,

V_o is the speed of a launch point on the surface of the earth, and $\varnothing$ is the angle between the launch azimuth and a line due east of the launch site

For a launch out of Baykonour into the ISSA orbit (51.6 degree inclination), V_1 = 1,060.6 cos (26.8) = 946.7 ft/sec

For a launch out of the Cape into the ISSA orbit,

V_1 = 1,339 cos (47.12) = 911.1 ft/sec

Thus, for launches into the ISSA orbit, Baykonour actually benefits more (946.7 – 911.1 = 35.6 ft/sec) from the rotation of the earth. (Launch azimuths to the ISSA orbit from the Cape and Baykonour were provided by the 45th Range Squadron, Cape Canaveral Air Force Station, Fla., and Ed Faudree of the ANSER Corporation, Washington, D.C., respectively.)

7. Craig Covault, "Reentry Flight Test Set for Second Ariane 5," *Aviation Week & Space Technology* 144, no. 13 (25 March 1996): 51–53.

8. The Titan IV can lift 39,100 pounds to LEO. Ariane 5 data may be found in "French Launcher Design: Evolved Ariane," *Military Space* 13, no. 5 (4 March 1996): 4. Titan IV data may be found in Bretton S. Alexander et al., "1994 Space Launch Activities," ANSER Aerospace Division Note ADN 95–2 (Arlington, Va.: ANSER, 1995).

9. See "National Reconnaissance Office Home Page," National Reconnaissance Office, n.p., on-line, Internet, available from http://www.nro.odci.gov/, for an official introduction to the US government's space-based national security reconnaissance capabilities.

10. There are numerous print and electronic media sources which contain information about US government space-based reconnaissance systems and provide ephemeris data which could be used to predict orbits and overflight times. This author makes no judgment about the accuracy of this publicly available information. However, if there is any truth to it, then even an unsophisticated adversary might thwart US attempts to monitor them using reconnaissance satellites in space.

11. Paul B. Stares, *The Militarization of Space* (Ithaca, N.Y.: Cornell University Press, 1985), 112–17.

12. Paul Jackson, ed., *Jane's All The World's Aircraft* (London: Jane's Information Group Limited, 1995), 617. The B-2 has a maximum weapons load of 40,000 pounds—the same as the payload weight capacity of RLV-B. However, when delivering weapons such as the AGM 169 advanced cruise missile (ACM), the joint direct attack munition, or the Mk 84 2,000-pound bomb, only 16 of these weapons can be carried due to the weight of the rotary launcher assembly required to carry and dispense them. Obviously, an RLV will not drop these same weapons. Weapons designed specifically for delivery from space will be required.

13. There are many assumptions underlying the numbers in this table. With respect to the RLVs, assumptions include a 100 percent mission capable rate, no other missions, such as spacelift, being accomplished, no losses, RLA carries eight 2,000-pound weapons and weighs

4,000 pounds, mission execution time is 90 minutes to go around the earth and return to launch base while making strike en route (45 minutes into orbit). With respect to the B-2, assumptions include a cost of $2 billion for each aircraft allowing for a cost-equivalent fleet of 10 aircraft (corresponds to RLV development budget of $20 billion), one-hour response time, 16 2,000-pound weapons delivered by each aircraft, flying out of the continental US (CONUS) with an 18-hour flight required to reach the target, recovery at the point of origin in the CONUS (Whiteman Air Force Base), and three-hour turnaround time. The $2 billion cost figure for each B-2 is a unit program cost—the total program cost divided by the number of aircraft acquired (see Jackson, 615). A lower cost figure for the B-2 could be used if one only counted the current unit production costs, not including program development costs. But then one could use the same method to arrive at a lower cost figure for RLVs as well.

14. At least one writer has suggested using an RLV-like vehicle to deliver US Marines "From Space" in the 2040 time frame. Maj William C. Redmond, "Campaign 2040: Victory From Space" (thesis, US Marine Corps School of Advanced Warfighting, 1995), 34.

15. Dave Schweikle, McDonnell Douglas Aerospace DC-X/DC-XA program manager, telephone interview with author, 2 April 1996, and personal observations of the author at White Sands Missile Range, 16–18 May 96.

16. Ibid., 2 April 1996.

17. Report of the Moorman Study, D–14.

18. Telephone inquiry to package delivery service, 3 April 1996.

19. Daniel McDonald, staff member, Aerial Ports Operations Division, Air Mobility Command, telephone interview with author, 4 April 1996. These cost and time figures averages are based on all shipments given a "999" priority, the highest possible, shipped from Dover to Ramstein during the period of October 1995 through February 1996.

20. For two examples, see Office of Space Systems Development, NASA headquarters, 70 and Report of the Moorman Study, 27.

21. Report of the Moorman Study, D-10–D-11.

22. National Research Council, *Reusable Launch Vehicle Technology Development and Test Program* (Washington, D.C.: National Academy Press, 1995), 13.

23. Ibid., 9.

24. Briefing, OL-AC PL/RKF (USAF Phillips Lab, Fundamental Technologies Division), subject: Integrated High Payoff Rocket Propulsion Technology program, 12 March 1996.

25. Recommendation #8 of the Moorman Study was to "increase funding for a core space launch technology program as an enabler for future investment" (see Report of the Moorman Study, 26). Funding for the IHPRPT program prior to the Moorman Study report was in the $50–60 million range—it has remained at that level since. James Chew, staff member, Directorate of Advanced Technology, director of Defense Research and Engineering, telephone interview with author, 19 March 1996.

26. The Moorman Study recommended "that the spacelift core technology program within DoD be increased from its current level to $120M total by FY 96" (see Report of the Moorman Study, C-1–3).

27. Jacob Neufeld, *Ballistic Missiles* (Washington, D.C.: Office of Air Force History, 1990), 208–19 and 234–35.

28. A cryogenic propellant is a liquefied gas at low temperature. Cryogenics are very high performance propellants (specific impulses as high as 450 seconds may be achieved) but are complicated to handle. Hypergolic propellants are liquid propellants which spontaneously ignite as the oxidizer and fuel come in contact with each other. Hypergolics like those used in the Titan are liquid at ambient temperature that can be stored for long periods in sealed tanks, easing some of the complications encountered with cryogenics, but only achieve specific impulses of 300–340 seconds. Solid propellants are simple, reliable, and relatively low cost, but have more limited performance (specific impulses of 300 seconds or less). George P. Sutton, *Rocket Propulsion Elements, An Introduction to the Engineering of Rockets* (New York: John Wiley & Sons, 1986), 147, 175, and 292. Larson and Wertz, 644–45.

29. Third Space Launch Squadron Operations Checklist, *AC-74 Launch Management Countdown Checklist*, 12 April 1994.

30. Schweikle.

31. Edward Boyle, Matthew Tracy, and Lt Col Donald Smoot, "Rethinking Support Equipment," *Air Force Journal of Logistics* 19, no. 4 (Fall 1995): 28–31.

32. Quoted in Boyle, Tracy, and Smoot, 28.

33. Quoted in Capt Sandra M. Gregory, "Improving Spacelift Reliability through Robust Design," *Air Force Journal of Logistics* 19, no. 1 (Winter 1995): 16–18.

34. Ibid., 16.

35. Report of the Moorman Study, 10.

36. Gregory, 17.

37. Bruce A. Smith, "Rockwell Completes Design of Key X-33 Components," *Aviation Week & Space Technology* 144, no. 13 (25 March 1996): 56–57.

38. Gregory, 17.

39. The McDonnell Douglas Aerospace and Rockwell RLV propulsion concepts plan on using SSME or RD-0120 derivative engines. The Lockheed RLV concept requires new engine development given its nontraditional linear aerospike engine design. Bachtel, telephone interview, 22 March 1996.

40. Joint Publication 3-14, "Joint Doctrine; Tactics, Techniques, and Procedures (TTP) for Space Operations," final draft, 15 April 1992, II-18–II-22 and A-1–A-17.

41. Stephen M. Walt, "Alliance Formation and the Balance of World Power," *International Security* 9, no. 4 (Spring 1985): 3–41.

42. Air Force Doctrine Document 4, "Space Doctrine," draft, 1 August 1995, 5.

43. It is interesting that prospect theory, a theory of how decisions are made, might suggest fear of loss is motivating NASA to be risk seeking in pursuit of RLV. NASA leaders fear losing the shuttle, so they will take the greater technical risk involved with developing a full-scale rocket instead of initially shooting for reusability in a smaller-scale vehicle. This is entirely speculative but may provide interesting insights into organizational behavior related to the RLV program. It may also suggest why the DOD would take a more risk-averse approach. The DOD sees development of an RLV as a potential gain, but is confident of its ability to continue using ELVs for space access. Thus, DOD is less motivated to take a high risk in the quest for an operational RLV. DOD pursues the lower-risk approach of incrementally improving its ELV fleet through the EELV program.

44. Quoted in Joseph C. Anselmo, "NASA Issues Wake-up Call to Industry," *Aviation Week & Space Technology* 144, no. 8 (19 February 1996): 20.

45. Ibid., 20.

46. Joseph C. Anselmo, "Clinton Budget Chops NASA Again," *Aviation Week & Space Technology* 144, no. 13 (25 March 1996): 23–24.

47. Lt Gen Howell Estes, director of operations, Joint Staff, "Operationalizing Space," address to the Second Annual C^4I Symposium, USAF Academy, Colo., 28 March 1996. Paul G. Kaminski, under secretary for acquisition and technology, "Building a Ready Force for the 21st Century," *Defense Issues* 11, no. 6 (17 January 1996): n.p., on-line, Internet, available from http://www.dtic.mil/defenselink/ pubs/di96/di1106.html. Rep. Ronald V. Dellums, "Toward a Post-Transition World: New Strategies for a New Century," *SAIS Review* 25, no. X (Winter–Spring 1995): 93–111. On the plus side, the DOD's 1997 budget request for space programs is up 12 percent in spite of the gloomy fiscal environment. Jennifer Heronema, "US Military Has Less, But Allocates More to Space," *Space News* 7, no. 10 (11–17 March 1996): 8.

Chapter 5

Conclusions

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

The United States and the Western World has 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

Introduction

Gen Bernard A. Schriever, commander, Western Development Division, a powerful force behind early developments in US military missile and space capabilities, was premature in predicting the importance of space battles, in a speech at San Diego, California, February 1957, although the future may prove him correct. Given the increasing importance of space support to recent battles on the land and sea, as well as in the air, his emphasis on achieving space superiority may be more appropriate today. However, it is ironic to read Lt Gen James A. Abrahamson's words—when he was director, Strategic Defense Initiative Organization—of almost 30 years later (Congressional Testimony, 23 July 1985). These remarks reflect the view of the top leader in development of the largest and most lethal space weapon system ever seriously considered for deployment. Yet he chose to emphasize the need for responsive and cost-effective space transportation, not weapons, as the key to future space activity of any kind. It is also interesting to note that the program which may be credited with inspiring the current pursuit of reusable rockets, the McDonnell Douglas DC-X, was started by General Abrahamson's organization.

Having derived RLV requirements, described RLVs and their attributes, elaborated two concepts of operations, and analyzed those CONOPS, conclusions may now be drawn in attempt to answer the initial research question. These conclusions are followed by recommendations and a summary of the research.

Conclusions

RLVs Have Military Potential. It is clear from both the CONOPS and the subsequent analysis that RLVs have potentially important military applications. In many ways, they can provide a multirole tool to help achieve the space superiority General Schriever discussed almost 40 years ago. An RLV's potential for accomplishing strike missions, especially to the surface, will be higher if turnaround and response times are shorter. Increasing the tempo of operations can make the force appear larger. Military missions also benefit from RLVs with greater cross-range capability allowing the kind of operations described by General Ashy.[1] Taking full advantage of RLVs' spacelift capabilities may require a paradigm shift in spacecraft design, deployment, and sustainment. The launch on demand strategy possible with an RLV is not in fashion today. Successful implementation of such a strategy will support space superiority but will require spacecraft ready to launch on short notice and ready to operate immediately upon deployment in orbit. These requirements could motivate development of cheaper, single-mission satellites since it may not be feasible to build and store billion-dollar multimission satellites, or to expect them to be operational immediately upon deployment.[2] Capitalizing on the RLV's ability to recover and return payloads, or to service them on orbit, would similarly require satellite design changes.[3]

RLV Design Effects. The potential impacts of RLV sizing have been addressed throughout this study. There is no unanimity regarding the proper size for an operational RLV. Nevertheless, many argue that the current size identified for a full-scale RLV as part of the NASA-led program involves high technical risk which means high financial risk as well. This study has suggested that derivatives of current propulsion systems will not deliver the performance levels required, or if they do deliver, there will be no performance margin and reliability will suffer. This assessment may be supported or proven false by further technology development and demonstrations. But due to the limited objectives of the X-33 flight tests, even these demonstrations may fail to give developers and investors the necessary confidence to go full scale. Perhaps the best course of action with respect to this issue is to ensure marketing analysts, developmental engineers, and operators remain in the closest contact to ensure the best RLV size is chosen.

The choice of RLV size must also be informed about the negative consequences and opportunity costs associated with each option. This study suggests that choosing smaller, cheaper RLVs can provide savings to apply towards a larger fleet and more bases. With such a force structure we can accomplish militarily significant activities to an extent not allowed by the choice of a smaller fleet and fewer bases. However, choosing a more militarily useful RLV design and force structure could result in negative consequences for commercial and civil operators. A more militarily useful RLV design might include increased thermal protection system requirements to facilitate the greater cross-range capability needed to takeoff and land at the same base after one orbit. It may also require the additional weight and cost of onboard self-protection systems. Meeting

these requirements will not be cost free. Whether the costs are in dollars, weight, or space, trade-offs will have to be made.

Propulsion Technology Development Needed. One way to mitigate some of the challenges faced in developing a full-scale RLV is to pursue propulsion technology development more vigorously. Regardless of the size chosen for an operational RLV, advances in thrust-to-weight ratios such as the 100 percent increase sought in the integrated high payoff rocket propulsion technology program can dramatically decrease technical and financial risk. Such efforts should be funded at the full level recommended by the Moorman Study. An investment of $120 million per year pales in comparison to the potential cost of developing an RLV. A lack of investment in propulsion technology development up front is bound to prove penny-wise and pound-foolish.

Top Priority Must Be Cheap and Responsive Space Access. While RLVs have tremendous potential to perform military missions well beyond simply conducting spacelift, an objective evaluation of priorities leads to other conclusions. The US military possesses tremendous strike and reconnaissance capabilities through existing and planned land, sea, and air systems.[4] Space-based reconnaissance has also been conducted since the dawn of the space age. What the US military, and the entire nation, does not possess is cheap and responsive space access. General Abrahamson's words quoted earlier were prophetic. Less than a year after his address, America's space access program literally crashed as a result of poor policy choices and a string of accidents that left the United States with a grounded STS fleet and a limited and unreliable ELV fleet. Talk of achieving space superiority is cheap. We must first have access to the space realm before we can begin to gain superiority there.

Recommendations

Three recommendations are offered here. First, the US military, especially the USAF, is already a participant in the RLV program, but it should become more active in this area. If, as this study assumes, today's fiscally constrained environment continues, the US military will not have the luxury of developing an RLV fleet independently. Accordingly, the US military will have to blend its requirements in with those of other users in order to pursue militarily significant applications. The current focus of the RLV program appears to be on NASA and commercial requirements. There is an implicit assumption that whatever is developed will spin on some military capability.[5] If the US military is a passive participant in the RLV program, then the assumed spin-on capabilities may be limited or nonexistent. Military requirements must be defined and stated if America is to develop a triple-use, rather than merely dual-use, RLV fleet. If the current fiscally constrained environment does not continue, then active participation in the current program is still warranted. An investment in defining military RLV requirements now will reap dividends should the time come when a military-unique RLV force can be developed.

Second, whether or not America develops a dual-use or triple-use RLV fleet or two fleets with one being military-unique, she should not do so before the

technology is ready. If this study's assumption that RLV technology will become operationally feasible by 2012 does not prove valid, then their development should not be pursued until the technology matures. The current RLV program appears to include this tenet, but NASA may be tempted to seek a high-risk development in order to acquire a shuttle replacement. For that matter, military space plane advocates may desire a similar approach in pursuit of a seemingly invincible weapon. Both parties undoubtedly have America's best interests at heart, but could lead us to squander our treasure in pursuit of a dream not yet ready to be realized. Careful evaluation of progress at each step in the program is the prudent course. The earliest opportunity, confidently to assess the merits of developing an operational vehicle, will not come until the turn of the millennium.

Third, regardless of the embryonic state of reusable rocket technology, it is not too early for the US military to think deeply about the implications of their operational use. If operational RLVs become a reality, there will be serious implications for war-fighting strategy, force structure planning, training, and doctrine. Concepts of operations should be developed in more depth and breadth than this study could achieve. In this regard, the analytical criteria used in this study may prove to be a useful framework for evaluating new RLV CONOPS. Another way to support preparation for the birth of operational RLVs is to keep military people active in the flight test programs. Today's DC-XA flight tests include uniformed personnel from the USAF's acquisition command.[6] It is not too soon to include operators and maintenance personnel in this activity. One of the often heard objectives of the RLV program is to develop aircraft-like operations. An excellent way to pursue this worthy goal would be to leverage the experience of seasoned military aircraft maintainers. A handful of senior crew chiefs working with RLV developers and test teams may provide helpful advice on how to establish efficient RLV generation and recovery systems and procedures. At the same time, these crew chiefs would also be developing a knowledge base for future military planning and operations.

Summary

The US military must be prepared to take advantage of reusable launch vehicles should the NASA-led effort to develop an RLV demonstrator prove successful. The focus of this study was an explanation of how the US military could use RLVs by describing and analyzing two concepts of operations. Four assumptions which guided the research are worthy of mention. First, the estimate that RLV technology will become operationally feasible by 2012 is reasonable. Second, a fiscally constrained environment will continue. Third, the US government will continue to support growth and development of the US commercial spacelift industry and encourage dual use, or perhaps triple use, of related facilities and systems. Fourth, the US government's national security strategy will continue to emphasize international leadership and engagement to further its political, economic, and security objectives.

Before developing and analyzing concepts of operations for military use of RLVs, requirements were stated as spacelift, reconnaissance, transspace operations, and strike (in and from space). Then, to provide a basis for CONOPS development and analysis, current RLV concepts and attributes were summarized, and hypothetical attributes of a notional RLV for use in military applications were suggested. Following discussion of RLV concepts and attributes, two concepts of operations were presented and subsequently analyzed. The criteria used in the analysis included capability, cost, operations efficiency and effectiveness, and political considerations (see table 5).

Four major conclusions resulted from the analysis. First, RLVs have military potential. Second, design choices for an operational RLV will have effects on risk,

Table 5

Summary of Analysis

Analytical Criteria	CONOPS A	CONOPS B
Capability		
Spacelift	Responsive, cannot lift all payloads	Responsive, lifts all payloads
Reconnaissance	Capable and responsive	Capable, but less responsive
Strike to Surface	Capable and responsive	Capable, but less responsive
Strike to Space (LEO)	Capable and responsive	Capable, but less responsive
Transspace	Capable—advantage of smaller propellant facilities	Capable—disadvantage of large propellant facilities
Cost		
Operating Base (nonrecurring cost)	At least $350 million	At least $150 million
ELV Augmentation	$26.6 billion through year 2030	None
Transspace	Not economically viable	Not economically viable
Technology Maturation	Decreases development costs—moderate requirement	Decreases development costs—essential
Operations Efficiency and Effectiveness		
Cryogenic Propellants	Complicates operations	Complicates operations
Deployment	Challenging—benefits from smaller propellant facilities	Challenging—suffers from large propellant facilities
Reliability	Good—lower propulsion performance requirement	Poor—lack of performance margin
Politics		
International	Lives within treaties and law–potentially threatening	Lives within treaties and law—less-threatening appearance
Domestic	ASAT ban prohibits space strike Fiscal constraints drive triple use	ASAT ban prohibits space strike Fiscal constraints drive triple use

cost, capability, and operations efficiency and effectiveness, the choice of a larger vehicle being accompanied by more risk. Third, increased investment in propulsion technology is warranted. Fourth, the top priority for the RLV program, even from the DOD perspective, should remain cheap and responsive access to space.

Three recommendations were offered. First, the US military should become a more active participant in the RLV program. Second, America should not pursue development of operational RLVs before the technology is ready. Third, it is not too early for the US military to think deeply about the implications of operational RLVs for war-fighting strategy, force structure planning, training, and doctrine.

The small steps being taken by the DC-X Delta Clipper-experimental in the New Mexico desert today may be recognized in coming years as having warmed and strengthened our muscles for the giant leap into an "exciting and vital future in space activities of all kinds."[7] America and her military must be prepared for that future.

Notes

1. Gen Joseph W. Ashy, CINCSPACE, identified the capabilities to "take-off on demand, overfly any location in the world in approximately one hour and return and land within two hours at the take-off base" as desirable. This was used as one basis for RLV requirements at the outset of this study (see chap. 1). Message, 221435Z Dec 95, commander, Air Force Space Command, to vice chief of staff, USAF, commander, Air Force Materiel Command, and commander, Air Combat Command, 22 December 1995.

2. The USAF Scientific Advisory Board's *New World Vistas* report describes a potential future in space where many low-cost single-function satellites work in cooperative networks to achieve even greater capability than that possible with a few high cost multifunction satellites. USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century,* Summary Volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995).

3. Wally McCoy, "Sustaining Space Systems for Strategic and Theater Operations," *Air Force Journal of Logistics* 19, no. 1 (Winter 1995): 32–33. The feasibility of on-orbit support has been studied within the military, as recently in 1993 by USSPACECOM, and made a reality by NASA through use of the space shuttle. The Hubble Space Telescope is one example of a spacecraft specifically designed for on-orbit servicing.

4. Report of the Moorman Study, "Space Launch Modernization Plan," 5 May 1994, C-1-2–3. If the ability to take off, overfly a target half-way around the world within an hour, and land back at the base of origin within two hours of takeoff is strongly desired by America's military leaders, then there may be a better way to obtain that capability. Scramjet technology, such as that developed as part of the National Aerospace Plane Program (HYFLITE) might be pursued to achieve TAV-like capability. This might also satisfy the deficiency in transspace operations as defined in the Spacelift MAP.

5. John A. Alic et al., *Beyond Spinoff, Military and Commercial Technologies in a Changing World* (Boston: Harvard Business School Press, 1992), 7–8, 73. The term *spin on* refers to reverse spin-off. With spin on, technologies developed entirely in the commercial sector are used, or are adapted for use, by the defense sector.

6. Maj Michael A. Rampino, personal observations at DC-XA flight test number nine, White Sands Missile Range, N.Mex., 16–18 May 1996.

7. Lt Gen James A. Abrahamson, quoted in House, *Assured Access to Space During the 1990's: Joint Hearings before the Subcommittee on Space Science Applications of the Committee on Science and Technology and the Subcommittee on Research and Development of the Committee on Armed Services*, 99th Cong., 1st sess., 1985, 41.

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