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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2006		**00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE **National Security Space Launch Report**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Rand Corporation,1776 Main Street,PO Box 2138,Santa Monica,CA,90407-2138**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**112**	

National Security Space Launch Report

The Congressionally Mandated National Security Space Launch Requirements Panel

Prepared for the Office of the Secretary of Defense

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RAND NATIONAL DEFENSE RESEARCH INSTITUTE

The research described in this report was prepared for the Office of the Secretary of Defense (OSD). The research was conducted in the the RAND National Defense Research Institute, a federally funded research and development center sponsored by the OSD, the Joint Staff, the Unified Combatant Commands, the Department of the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community under Contracts DASW01-01-C-0004 and W74V8H-06-C-0002.

Library of Congress Cataloging-in-Publication Data

National security space launch report / Forrest McCartney ... [et al.].
p. cm.
"MG-503."
Includes bibliographical references.
ISBN-13: 978-0-8330-3959-0 (pbk. : alk. paper)
1. Astronautics and state—United States. 2. Astronautics, Military—United States. 3. National security—United States. 4. Launch vehicles (Astronautics)—United States. 5. United States. Dept. of Defense. I. McCartney, Forrest.

TL789.8.U5N315 2006
358'.80973—dc22

2006022599

Published 2006 by the RAND Corporation
1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
4570 Fifth Avenue, Suite 600, Pittsburgh, PA 15213-2665
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Preface

On January 20, 2004, Congress in House Resolution 4200 directed the Secretary of Defense to establish a panel of experts with extensive space launch and operations background to address the future National Security Space (NSS) launch requirements and the means of meeting those requirements. The Department of Defense (DoD) selected the RAND Corporation to facilitate and support this panel in its deliberations between May 2005 and May 2006. The specific congressional directive and the panel members with their background are contained in Appendixes B and C. Additionally, a summary of the National Space Transportation Policy, a key document in exploring this subject, can also be found in Appendix B.

This report should be of interest to members of Congress and their staffs, civilian and military officials in DoD, and leaders of the aerospace industry.

This research was sponsored by the Office of the Secretary of Defense and conducted within the Acquisition and Technology Policy Center of the RAND National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Department of the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community.

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In Memoriam

The Panel wishes to acknowledge the extensive contributions to this report made by Maj Gen Jimmey Morrell, USAF (Ret.). His insights and advice were a critical part of this study. The report was in the final phases of draft review when Jimmey died on February 8, 2006. The space community has lost one of its "pioneers," and his counsel will be missed by all of us.

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Introduction

On January 20, 2004, Congress in House Resolution 4200 directed the Secretary of Defense to establish a panel of experts with extensive space launch and operations background to address the future National Security Space (NSS) launch requirements and the means of meeting those requirements. The Department of Defense (DoD) selected the RAND Corporation to facilitate and support this panel in its deliberations between May 2005 and May 2006.

After a comprehensive review and assessment of the future NSS launch requirements, the National Security Space Launch Requirements Panel concluded that the Evolved Expendable Launch Vehicle (EELV) program can satisfy all known and projected NSS requirements through 2020.

The yearlong fact finding and analysis (between May 2005 and May 2006) of this Panel derived many findings on NSS requirements and the means of satisfying them. We introduce them here. A more complete account of the Panel's findings and judgments is found in the body of this report, and, accordingly, a study of the entire document is recommended.

The National Space Transportation Policy (NSTP) of 2004 is clear in declaring reliable and affordable launch "a fundamental goal of the U.S. space program." Given the national security reliance on space services, that is an unarguable position and one that served to guide the Panel throughout the study.

The Panel work commenced with a review of known and potential scientific developments that might lead to fielding a radical breakthrough in space launch during the next 15 years. We uncovered no evidence that such a breakthrough would emerge before 2020. The basic rocketry principles, use of chemically derived thrust, and multiple expendable stages seem certain to remain the design of choice for operational space launch vehicles in the years covered by this study.

Background

Any consideration of future NSS launch requirements must begin with at least a partial description of key decisions and events that led to the existing policy environment. Since the commencement of the space age 50 years ago, the U.S. government has relied on robust launch capabilities to support crucial defense and intelligence missions. These launchers have been key technology enablers underpinning virtually all space activities. Preserving our ability to provide assured space services is critical to maintaining U.S. national security.

By the end of the Apollo era, the U.S. government recognized that the cost of reaching space was so high that it threatened the nation's ability to take full advantage of its space technology and proven capabilities. The National Aeronautics and Space Administration (NASA) was authorized to address this economic challenge by building a National Space Transportation System (now known as the Space Shuttle), which was intended to reduce costs and improve reliability by employing a largely reusable vehicle that would serve as a launch vehicle, spacecraft, and earth recovery system. From the inception of the Shuttle program, it was recognized that high traffic volume would be necessary to enable reducing the cost of access to space. Accordingly, the U.S. government directed that all U.S. payloads, including national security payloads, be launched with the Shuttle and that the existing fleet of Expendable Launch Vehicles (ELVs) be retired. Following the *Challenger* accident in 1986, the U.S. government established a policy that national security payloads would not be dependent on the status of a single-launch vehicle. As a result, the U.S. government relied on existing ELV families with complementary launch capabilities. These legacy systems became the Titan IV, Atlas II, Delta II, and several small vehicles in the Titan II and Pegasus classes.

Widespread concerns about the high cost of Titan IV operations led to initiation of the EELV program in the early 1990s.[1] In August 1994, in recognition of the vital role played by space transportation systems, the Clinton administration issued National Science and Technology Council–4, commonly known as the 1994 NSTP. The directive stated that assuring reliable and affordable access to space was a fundamental goal of the U.S. space program. To this end, the policy mandated that appropriate government agencies work to maintain strong launch systems and infrastructure while modernizing space transportation capabilities and encouraging cost reductions.

The task delegated to DoD was to improve the existing ELV fleet, while NASA was charged with sustaining the Shuttle and developing the technologies necessary for next-generation reusable launch vehicles.

In October 1994, the U.S. Air Force was selected as the executive agency for the newly created EELV program. The objective of the project was to develop a national space launch system capable of reliably satisfying the government's national mission model requirements while reducing space launch costs by at least 25 percent. Under the EELV program's original acquisition strategy, the Air Force would select a single contractor. In November 1997,

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[1] Paul G. Kaminski, Under Secretary of Defense for Acquisition and Technology, "Space Forces Essential to Modern Military," prepared statement to the National Security Subcommittee, House Appropriations Committee, March 23, 1995.

however, a new acquisition approach was adopted because it was determined that a larger than previously envisioned commercial market would support two contractors. The intent was that this new arrangement would create two vehicle families capable of meeting government requirements while also capturing commercial launches, which would result in lower mission costs and higher reliability for all. Consequently, the third phase of the EELV program began in October 1998 when commercial development contracts were awarded to both Boeing and Lockheed Martin. The DoD cost share of the EELV development was $1 billion, split evenly between the two prime contractors. This final phase included engineering and manufacturing of the launch system, launchpads, satellite interfaces, and support infrastructure.

Currently, the EELV program consists of two families of launch vehicles as well as associated launch infrastructure and support systems. Lockheed Martin's Atlas V family is built around a Common Core Booster powered by the Russian-built RD-180 engine; it began operations in August 2002 and has completed eight successful flights with no failures. Boeing's Delta IV family is built around a Common Booster Core powered by the Pratt & Whitney Rocketdyne RS-68 engine; it began operations in November 2002 and has completed six successful launches (although one flight had a correctable anomaly). Both the Atlas V and Delta IV families employ the RL-10 engine for their upper stages. Both vehicles can be launched from Cape Canaveral Air Force Station, Florida, and Vandenberg Air Force Base, California.

In December 2004, the Bush administration issued a new NSTP. The directive adopted the link between assured access to space and the need for two EELV launch families. The document states, "The Secretary of Defense … shall fund the annual fixed costs for both launch service providers until certifying to the President that a capability that reliably provides assured access to space can be maintained without two EELV providers."

In July 2005, in response to the NSTP, NASA Administrator Michael Griffin and Under Secretary of the Air Force Ron Sega reached an agreement[2] regarding the development and use of future launch vehicles. Because of this arrangement, the potential future addressable EELV launch market may include NASA science spacecraft, ISS cargo resupply missions, and commercial satellites. Human exploration missions will not be part of the EELV requirements. (See Appendix B.)

Assessment

From the Panel's first day of deliberations, it has been apparent that the space launch capability inherent in the two EELV families of U.S. rockets (Atlas V and Delta IV) are state-of-the-art technology achievements gained through combined industrial and DoD investment. While these rockets are still comparatively early in their maturation cycle, their performance suggests that they can become workhorse launch vehicles for the future. Both families are supported by modern facilities and capable personnel from manufacturing to launch. Ample evidence

[2] Michael D. Griffin, NASA Administrator, and Ronald M. Sega, DoD Executive Agent for Space, "Space Transportation Strategy," letter to John H. Marburger III, Director, Office of Science and Technology Policy, Executive Office of the President, August 8, 2005. (See Appendix B.)

suggests that these rockets can meet the NSS launch needs of the United States through 2020 (the end of the study period), barring the emergence of payload requirements that exceed their design lift capability. Whatever decisions are taken concerning the future of these rockets, the going-in position should be that they are superior in their current condition and that no managerial actions should be taken in ways that would adversely disturb this known and hard-earned condition.

It is noteworthy that, however capable these rockets, they do not compete on a price basis with those of many foreign launch providers, which all enjoy substantial subsidies and often benefit from skilled labor rates far below those of the United States. Those fiscal realities have made these rockets largely uncompetitive in today's commercial market, and it is unlikely they will capture more than a small number of commercial launch contracts in the future. Therefore, the U.S. government must be prepared to bear virtually the entire financial burden of retaining either or both of these rocket families for the period we evaluated (2005–2020). Further, given that the U.S. government is the only likely customer, the probability that launch demand may drop below a demand that will sustain team proficiency for two families is increased, giving rise to questions of reliability that often stem from low production rates. It also forces contemplation of the inevitable question of whether it is prudent for the U.S. government to underwrite both rocket families over the long term. Determining how many EELV launches the U.S. government will procure each year over the next 15 years is inexact. With the cost and complexity of NSS payloads, the prospect of ever-increasing on-orbit life, increased procurement of commercial space services, and the potential for dual payloads, the ultimate number of NSS launches is far more likely to decrease than to grow.

In addition to evaluating potential commercial launch customers for EELV, the Panel explored other U.S. government users outside the national security realm that might employ the EELV. The possibility exists that NASA could use the EELV to launch unmanned flights to resupply the International Space Station (ISS), perform science missions, and fulfill other space launch requirements. NASA did not select the EELV to fulfill its post-Shuttle human space flight requirements. NASA did, however, agree to use the EELV for civil, science, and ISS cargo resupply missions in the 5- to 20-metric-ton class to the maximum extent possible. The potential for cost savings at the U.S. government level, and the increased reliability due to an expanded launch manifest that would result from NASA's use of the EELV, argues strongly for cooperative launch planning between DoD and NASA.

The NSTP directs that, for the foreseeable future, capabilities developed by the EELV program will be the foundation for U.S. government access to space. It also states that new U.S. commercial space transportation capabilities that demonstrate reliable launch will be allowed to compete for U.S. government missions. The Panel supports inclusion of new entrants but notes a lack of definition concerning how a new development would be selected, or qualified, for inclusion in the manifest. Eliminating the potential for unfounded expectations, both in the U.S. government and by potential offerers, requires timely promulgation of a clear set of technical and programmatic guidelines regarding new commercial entries.

In the late 1990s, those in government and industry had good reason to believe that the combination of U.S. government launch demand and the promise of large numbers of commercial launches would allow the development of two rocket families within the EELV budget, thereby preserving the “assured access to space” policy that was adopted after the *Challenger* accident. The U.S. government invested $1 billion, split evenly between Atlas and Delta developments. The U.S. government anticipated that the two parent companies, Lockheed Martin and Boeing, would also invest heavily in their respective EELV development, which they did. These costly and complex developments, which the U.S. government is now the beneficiary of, were driven in large part by the two companies’ desire to be positioned to profit from the expected large launch service buys, driven mainly by commercial demand. The dramatic collapse of the commercial launch demand in the late 1990s and early 2000s, however, left these two EELV families vying for few commercial launches at the same time the number of U.S. government launches was diminishing. The U.S. government intervened to preserve program integrity and to transition from its initial reliance on firm-fixed-price contracts for commercial products to a traditional contract far more suited to the procurement of specialized government products and services. The NSTP directed the Secretary of Defense to fund the annual fixed costs of both contractors until such time that it can be a certified that assured access to space can be maintained without two EELV families. Accordingly, a new contract for EELV launches, called “Buy 3,” will cover missions scheduled to launch between 2008 and 2012. Both the cost-plus launch capabilities contracts and the firm-fixed-price launch services contracts are planned to begin between April and June 2006.

The defining concept currently underpinning the dual-family EELV is the need for assured access to space. The essence of the EELV operational concept is to provide high assurance of NSS launch services to payloads deployed on a well-defined “launch-on-schedule” plan. This is in contrast to the Operationally Responsive Space (ORS) concept, which is based on “launch on demand” as determined by largely unplanned operational needs of the end user.

The reliance of the United States on space services to meet national security needs argues strenuously for capable and reliable launch. The reliability argument has led the United States to retain two EELV families so that one might reasonably be available in the event of a systemic failure in the other. The losses of *Challenger* and *Columbia*, and corresponding long grounding periods of all the Shuttles following those accidents, seem to underscore the need for this diversity. This Panel does not challenge the need for NSS launch surety but notes that the history of modern expendable rockets being truly “out of commission” for extended periods is sparse. In those cases in which the decision was to delay launch for long periods, as happened with the Titan IV in the late 1990s, it was not so much a case of not being able to launch sooner but rather a conscious choice because the luxury of delay existed. Our analysis suggests that extended delays in payload delivery are far more common than delays caused by rocket availability. Indeed, we regularly learn of delays in the projected launch dates for a number of high-visibility NSS payloads, some measured in years. In that environment, it is not proper to describe “assured access” solely in terms of space launch when in fact it is payload availability that almost invariably is the greater determinant. If assured access is to remain the mantra of NSS, then an analysis of all the elements that make up that concept should be conducted, including payload availability and the possibility of flying through failure. Lastly, for the concept of “assured access” derived from the use of multiple rocket families to be credible, virtually all payloads must be capable of rapid configuration for manifest on all NSS launchers. That is not currently the case and is not planned for some critical payloads.

Further related to the issue of assured access, the Panel contemplated the likely long-term reliability of the two rocket families. In addition to their early demonstrations of reliable performance, both families are produced by companies with a long history of building and flying reliable launch vehicles. The nature of these designs and the extensive certification process used by the U.S. government make it unlikely that either would suffer a systemic failure that could not be resolved in a time frame suitable to meet NSS launch needs. The Panel also believes that the normal anomalies detected during early flights will be adequately addressed but will require close tracking.

The Panel was aware of the United Launch Alliance (ULA) proposal throughout its deliberations but took no position because it was projected that a ULA decision would be taken before this report was published. Nevertheless, and as stated earlier, the U.S. government will be virtually the sole user of EELV products and services, and the sole source of funding for this enterprise, giving the U.S. government both the freedom and the obligation to carefully monitor and manage it. The panel understands that current plans require contracting for additional launches scheduled to begin as early as 2010 ("Buy 4"). Therefore, the U.S. government must quickly acquire deep and unfettered insight into the technical and financial records of this enterprise. A comprehensive cost and performance database is essential to making informed decisions relative to the future course of action, which must be made early enough to allow implementation without schedule disruption. A clear view of the cost to own and operate these two families cannot be determined with confidence until the systems have matured and sufficient data are available for evaluation. These concerns led the Panel to conclude that cost of ownership must be considered along with reliability in determining the proper course of action regarding long-term EELV decisions. It is the Panel's view that a decision regarding the path ahead should be taken as soon as sufficient reliability data are amassed and the true costs of ownership are known. To be consistent with the NSTP, a target date of 2010 should be established for implementation of these decisions.

Other major issues that must be dealt with in determining an appropriate course for the EELV program focus on heavy-lift requirements and the use of the Russian-built RD-180 engine on the Atlas V. The Panel recognizes the desirability of maintaining a heavy-lift capability to provide growth margins for future payloads but believes that such requirements warrant revalidation in light of a budget environment that is anticipated to be austere. The paucity of hard heavy-lift requirements, the tenuous nature of projected requirements, and the absence of a heavy-lift variant of the Atlas family make this a key consideration in defining the course ahead. The potential for coproducing the RD-180 engine in the United States exists, but very substantial investment and several years of engineering development remain for that to become a reality. Another issue to be confronted in the years ahead is both families' reliance on the RL-10 upper-stage engine. Each of these is made complex by a combination of existing policy, the need for substantial additional investment, and a desire to enhance diversity in these two families. We include a more detailed discussion of these and related issues in Chapters Three and Four of this report.

The U.S. government has also held discussions with the Space Exploration Technologies Corporation (SpaceX) concerning the potential for procurement of its Falcon rocket family, with the understanding that if its larger versions prove affordable and reliable, then they will be allowed to compete with EELV. The Panel believes that such an approach is consistent with the provisions of the NSTP and that the incremental block "Buy 1, 2, 3" process is an appropriate vehicle for keeping the door open for qualified emerging entrants.

Within DoD, much attention has been given to the concept of ORS as a means of meeting the rapidly emerging space needs of the modern warfighter. Furthermore, the NSTP directs demonstration of an initial capability for operationally responsive access to and use of space to support national security requirements before 2010. The Panel acknowledges the potential benefit of such a capability but found little hard documentation that equated to a verifiable need. It is the position of the Panel that embarking on an extraordinary effort to develop a launch system more responsive than those that already exist would not be cost-effective until needs are clearly stated, operational concepts are defined, and, most importantly, a family of candidate payloads is within view.

The remainder of this decade will be critical to the NSS launch architecture as the two families mature and knowledge is gained that will be vital to EELV decisions. Anticipating that near future, several EELV issues must be addressed now, including the use of Russian hardware, quantifying the need for heavy-lift capability, common reliance on the RL-10 upper-stage booster, the formulation of specific criteria for commercially supplied space launch, and the need for extensive data gathering on the two EELV families. With successful resolution of these and a modest list of additional issues identified in this study, the EELV program should be counted on to be capable of fulfilling the nation's NSS launch needs for the next several decades.

Findings and Recommendations

Finding 1

While the Atlas V and Delta IV families are early in their operational lives, their developmental legacy, introduction of modern manufacturing and avionics, and flight records to date have been successful. The Panel found the technology embedded in these two rocket families to be commendable, with the promise of meeting NSS needs through 2020 and beyond.

The EELV families (with their supporting manufacturing, processing, and launch infrastructure), the current technology base, the current industrial base, and the ranges (with the planned level of funding and improvements) will satisfy the known and projected NSS mission requirements.

Recommendation 1A: The EELV development programs are true successes and are critical to national security. The Air Force must rigorously protect this capability with resources adequate to sustain these programs. Any additional launch developments must be supported with funding separate from EELV.

Recommendation 1B: The Air Force must fund EELV launch and range infrastructure sufficient to implement planned acquisition strategies.

Finding 2

The U.S. government is likely to be virtually the only EELV customer and must be prepared to bear the full cost of ownership. It is unlikely that more than a minimal commercial market will develop for the EELV.

The national launch forecast in the latter years of this study tends toward lower and lower numbers. EELV manufacturing and launch cadre proficiency will benefit from an increase in the number of annual launches. The provisions of the NSTP regarding required U.S. government use of the EELV make clear the goal of employing the EELV for U.S. government needs beyond classic NSS manifests.

Recommendation 2A: The EELV program would benefit from increased government usage. NASA and DoD should rigorously apply the NSTP with a going-in goal of utilizing EELV for NASA ISS resupply and science missions.

Recommendation 2B: The EELV program would benefit from increased commercial launches. The U.S. government should address measures that will aid the EELV to compete in the price-driven commercial launch marketplace.

Finding 3

The Atlas V and Delta IV were developed with substantial private investment to serve a large commercial market as well as U.S. government customers. Accordingly, the U.S. government initially procured these systems on a commercial basis, making insight into their design and development limited compared with programs intended for near-exclusive U.S. government application. With the U.S. government now postured as virtually the sole user of the EELV, with corresponding needs for a comprehensive understanding of the cost and reliability drivers, more thorough insight is required.

Recommendation 3A: The Air Force should immediately commence a thorough evaluation of the designs of the EELV flight hardware and ground processing and launch facilities to identify needed modifications and the costs associated with the total cost of ownership.

Recommendation 3B: The Air Force should immediately initiate the necessary contract changes for data rights and enabling clauses in order to collect the data required to evaluate the performance and ownership costs of each of the EELV families (Atlas V and Delta IV).

Finding 4

The EELV program represents a major management challenge—with or without the advent of ULA. The next few years are critical in gathering the required data on which to base an objective decision regarding the "path ahead" for this critical national resource.

Recommendation 4: The Air Force should identify the extraordinary management actions and senior review processes required to execute the planned EELV program strategy and then ensure that the leadership and properly skilled technical and program management personnel to direct the program are in place. This may involve placing U.S. government personnel within the respective EELV companies (and ULA, as appropriate) to gather the necessary data and insight.

Finding 5

A great deal of attention has been devoted to evaluating how well the EELV families have satisfied their original intent. Nevertheless, after a decade of development, it is more important to determine today's projected requirements than to evaluate how well yesterday's requirements were met. Accordingly, it is appropriate to revalidate the requirements for heavy lift, assured access, and issues regarding the Atlas V's use of Russian-built engines in parallel with the cost and performance assessments described in Recommendations 3A and 3B. These issues are complex and must be addressed in the very near future to allow formulation of a strategy that meets cost, reliability, and operational needs in time to be implemented in the 2010 time frame. This strategy must consider a broad range of options, including (1) retaining both the Atlas V and the Delta IV, (2) selecting the superior launch vehicle, or (3) using an acceptable EELV alternative if such a capability exists.

Recommendation 5A: The Air Force and the National Reconnaissance Office should immediately (a) determine the necessity of an EELV heavy-lift variant, including development of an Atlas V Heavy, and (b) resolve the RD-180 issue, including coproduction, stockpiling, or U.S. development of an RD-180 replacement.

Recommendation 5B: The U.S. government should develop criteria to be applied in soliciting and potentially selecting EELV alternative vehicles. These criteria should be made available to prospective suppliers so as to manage expectations and eliminate perceptions of U.S. government endorsement where none was intended.

Finding 6

The use of the RL-10 as a common component in the upper stage of both the Atlas V and Delta IV has been raised as a potentially troubling source of a single-point failure. A failure that affects the RL-10 will most likely ground both vehicles.

Recommendation 6: Since the RL-10 is common to both EELV families, the Air Force should immediately assess and then implement appropriate product improvements to reduce risk.

Finding 7

Experiments and studies are in progress by the Air Force and the Defense Advanced Research Projects Agency to demonstrate ORS concepts and requirements in accordance with the NSTP. Development of launch system capabilities beyond those available today should proceed at a pace in consonance with the development of requirements, concepts of operations, and operationally useful payloads. Although experiments may be conducted sooner, the current level of the ORS definition makes it likely that initial operational capability (IOC) for any such system will occur post-2015.

Recommendation 7: The U.S. government should continue the ORS experiments and demonstrations. However, ORS full-scale development should not be undertaken until an operational concept, a family of candidate payloads, and launch vehicles and infrastructure are aligned.

Finding 8

No new technology is required to meet NSS launch requirements through 2020, although advancements will surely be incorporated. However, austere budgets that limit technology developments to those required for satisfying immediate requirements pose the threat of shortfalls in launch-related technologies and the industrial base needed to support future system developments.

Recommendation 8: The U.S. government should identify post-2020 NSS requirements so that key technologies and related industrial efforts can be identified and supported.

Acknowledgments

The National Security Space Launch Requirements Panel wishes to acknowledge and express its appreciation to the RAND Corporation for its support and to the many individuals involved in fact-finding presentations to the Panel. A bibliography of these presentations can be found in Appendix D.

Abbreviations

AEHF	Advanced Extremely High Frequency
AFB	Air Force Base
AFRL	Air Force Research Laboratory
AFS	Air Force Station
AFSPC	Air Force Space Command
ASOC	Atlas Space Operations Center
CBC	Common Booster Core (Delta)
CCB	Common Core Booster (Atlas)
DARPA	Defense Advanced Research Projects Agency
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
DSCS	Defense Satellite Communications System
DSP	Defense Support Program
EELV	Evolved Expendable Launch Vehicle
ELV	Expendable Launch Vehicle
FALCON	Force Application and Launch from the Continental United States
FAR	Federal Acquisition Regulation
FTC	Federal Trade Commission

FY	fiscal year
GAO	Government Accountability Office (formerly General Accounting Office)
GEO	geosynchronous earth orbit
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
IOC	initial operational capability
ISS	International Space Station
KPP	Key Performance Parameter
LEO	low earth orbit
MUOS	Mobile User Objective System
NASA	National Aeronautics and Space Administration
NGLT	Next Generation Launch Technology
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NRO	National Reconnaissance Office
NSS	National Security Space
NSTP	National Space Transportation Policy
O&M	operations and maintenance
ORD	Operational Requirements Document
ORS	Operationally Responsive Space
PIA	Procurement Integrity Act
PNT	positioning, navigation, and timing
R&D	research and development
SAF/USA	Directorate of Space Acquisition

SBIRS	Space-Based Infrared System
SBSS	Space-Based Space Surveillance
SLC	Space Launch Complex
SLI	Space Launch Initiative
SpaceX	Space Exploration Technologies Corporation
SSME	Space Shuttle Main Engine
SSO	sun-synchronous orbit
STSS	Space Tracking and Surveillance System
TDRS	Tracking and Data Relay Satellite
TSAT	Transformational Communications Satellite
UFO	Ultra-High Frequency Follow-On
ULA	United Launch Alliance
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
VIF	Vertical Integration Facility
WGS	Wideband Gapfiller System

CHAPTER ONE

Baseline National Security Space Requirements

On January 20, 2004, Congress, in House Resolution 4200, directed the Secretary of Defense to establish a panel of experts with extensive space launch and operations background to address the future National Security Space (NSS) launch requirements and the means of meeting those requirements. The Department of Defense (DoD) selected the RAND Corporation to facilitate and support this panel in its deliberations between May 2005 and May 2006.

Tasking

This chapter responds to specific tasking from House Resolution 4200: "The report shall include … findings and conclusions of the panel on the future NSS launch requirements of the United States, including means of meeting such requirements."

Discussion

Space Launch: A Derived Requirement

Space launch itself is not a requirement. Rather, space launch provides access to space, where satellite systems provide services critical to national interests. Launch requirements, therefore, exist only as they are derived from space services' requirements.

Defining NSS Launch Requirements

The President authorized a U.S. Space Transportation Policy on December 21, 2004, that established national policy, guidelines, and implementation of U.S. space transportation programs and activities. This policy provided broad directions and specified that "for the foreseeable future, the capabilities developed under the Evolved Expendable Launch Vehicle [EELV] program shall be the foundation for access to space for intermediate and larger payloads for national security, homeland security, and civil purposes to the maximum extent possible consistent with mission, performance, cost, and schedule requirements."[1] Accordingly, the launch demand imposed by government organizations other than those responsible for national secu-

[1] National Space Transportation Policy of 2004. (See Appendix B.)

rity must also be considered when assessing the EELV program's ability to satisfy NSS launch requirements.

NSS Services

As mentioned earlier, NSS launch requirements and schedules are derived from the need to sustain on-orbit capability for critical national security services. U.S. NSS services can be divided into positioning, navigation, and timing (PNT); communications; and earth observation (including classified missions).

Positioning, Navigation, and Timing

The current U.S. satellite-based PNT architecture consists of a 24-satellite Global Positioning System (GPS) constellation operating in six different orbital planes in medium earth orbit, approximately 20,200 kilometers from the earth. In addition to providing PNT services to the combat forces, GPS offers positioning capabilities used extensively by aircraft and marine vessels for automated landing and harbor approaches. The precision timing aspects of GPS are even more widely used, with applications in wireless ground communications, authentication of electronic transactions, and management of large computerized networks, including power and communications grids. The Air Force replenishes the system as required to ensure that each of the six planes contains a minimum of four functional satellites, thus sustaining full-service capability. The GPS IIR-M satellites currently being launched will be followed by GPS IIF beginning in 2007. The first of the GPS III satellites is expected to launch in 2013.[2]

Communications

Communications services are categorized in three major groups: wideband, protected, and narrowband. A fourth, supplementary group of data-relay satellites operates in support of all these groups. It is difficult to create a comprehensive picture of all DoD communications requirements because a large number of variables complicate the analysis. The communications sector differs from other services in that its capacity cannot be measured merely by the number of satellites. For example, even if an adequate number of satellites can provide earth coverage, they may not transmit at the correct frequency, they may not supply sufficient bandwidth, or they may only be capable of establishing one-way data connections. For the purposes of analysis, however, the Panel addressed communications requirements only in the context that they drive launch requirements—that is, with respect to defined NSS programs during the 2005 to 2020 time frame.

Earth Observation

The broad category of earth-observing satellite services consists of three smaller service families, each of which includes specific programs that require unique orbits. The three families include reconnaissance, missile warning and defense, and weather monitoring. An array of classified satellite programs operated by the National Reconnaissance Office (NRO) provides current U.S. spaceborne reconnaissance services. DoD currently sustains its own military weather

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[2] Directorate of Space Acquisition (SAF/USA), "EELV Launch Schedule: FY06 PBR," November 29, 2005.

services under the Defense Meteorological Satellite Program (DMSP) and its planned successor, the National Polar-Orbiting Operational Environmental Satellite System (NPOESS). DoD also relies on data transmitted from the civilian-launched Geostationary Operational Environmental Satellite (GOES) and the National Oceanic and Atmospheric Administration (NOAA) satellites. Missile warning and defense services include the Space-Based Infrared System (SBIRS) program (the replacement for the Defense Satellite Program early-warning satellites), the Space Tracking and Surveillance System (STSS), and the Space-Based Space Surveillance (SBSS) system.

A Baseline Requirements Manifest

Detailed planning documents have been provided to the Panel by the Directorate of Space Acquisition (SAF/USA), the Air Force Space Command (AFSPC), the NRO, and the National Aeronautics and Space Administration (NASA).[3] From these data, the Panel has compiled a comprehensive manifest that reflects the U.S. government's launch requirements. This manifest, shown in Appendix A, segregates requirements into three user categories: NSS (satellites used by DoD or the Intelligence Community), non-NSS services (U.S. government science and technology satellites), and human space flight. It further categorizes NSS and non-NSS services by functional categories (PNT, communications, and earth observation).

For the sake of consistency, the Panel identified all Atlas V variants that use a Common Core Booster (CCB) and all Delta IV variants that use one Common Booster Core (CBC), as an EELV, regardless of the number of solid rocket motors used. Only the Delta IV has a three-CBC heavy-lift variant, which is identified as an "EELV Heavy." See Chapter Three for further discussion of EELV nomenclature.

Examination of Appendix A shows an uneven demand distribution, with a dramatic reduction in NSS missions beginning around 2013. One contributor to this out-year trend is the government budget process, which makes it difficult to formalize program details 10 to 15 years in advance. However, because the mission of operational NSS systems is to provide assured services, further analysis is required to project NSS launch requirements to the end of the study period.

Assessing NSS Launch Requirements

Appendix A depicts current launch projections. However, several real-world factors influence the actual schedule. First, because these projections are based on the current Future Years Defense Program, there is only a limited basis for estimating activity beyond 2012. Second, because the current launch strategy is to ensure "launch on schedule" (see Chapter Five), the need to replace existing satellites is based on the health of the constellation as judged at the time of scheduled launch or the need for and availability of new capabilities. Experience has shown that, in most cases, mature satellite designs can be expected to operate significantly beyond their design life, although replacements must be scheduled for launch much earlier to

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[3] Throughout the Panel's analysis, manifest information supplied by SAF/USA was considered definitive through the FY 2013 time frame. Manifests supplied by U.S. Space Command and the NRO were used only to supplement this material in the extended time line. NASA documents were used only for analysis of civilian-launched payloads.

avoid risking a loss of critical service. Third, virtually every service category is scheduled to introduce a new generation of satellites, with longer design life and greater capacity, between 2005 and 2020 (as shown in Figure 1.1).[4]

Figure 1.1 depicts legacy systems in light blue and new-generation capabilities in dark blue. History shows, however, that deployment of new designs has a relatively high probability of being delayed. The yellow bars in the figure represent an increasing use of commercial communications and imagery to augment similar services provided by the NSS service programs.

All these factors, taken together, suggest that the total number of NSS launches required between 2006 and 2020 is likely to be the same as depicted in Appendix A but distributed more evenly across the study period. Should this turn out to be the case, the EELV demand will average five launches per year for NSS service missions and seven launches per year for the entire projected manifest, rather than the eight-per-year and ten-per-year values indicated, respectively, by Appendix A for the 2006 to 2012 period.

The Panel was briefed on a number of new capabilities and potentially high-priority NSS service requirements. These concepts, however, are at such an early stage of development that it seems unlikely that significant new launch requirements, other than for research and development (R&D) missions, will emerge before 2015.[5]

If space launch is viewed as a "just in time" logistics mission, then the launch systems must be able to accommodate both the highest and the most probable launch rate projections. The Panel believes that the current launch schedule, shown in Appendix A, represents the high demand and that the reduced average, previously discussed, represents a more likely level.

Demand Analysis

Forecasting the future is always difficult, and the further into the future, the more difficult the challenge becomes. Appendix A reflects only currently acknowledged and funded programs. It defines NSS service missions as those that have proven critical to national security and must be maintained. R&D efforts in support of long-term NSS objectives, however, are categorized as non-NSS service missions because the nature of their missions is evolutionary and difficult to define very far in advance.

The following figures summarize Appendix A launch requirements: Figure 1.2 depicts launch requirements divided into NSS service and non-NSS service payloads; Figure 1.3 shows NSS service launch requirements by launch vehicle size; and Figure 1.4 shows NSS service requirements by launch site.

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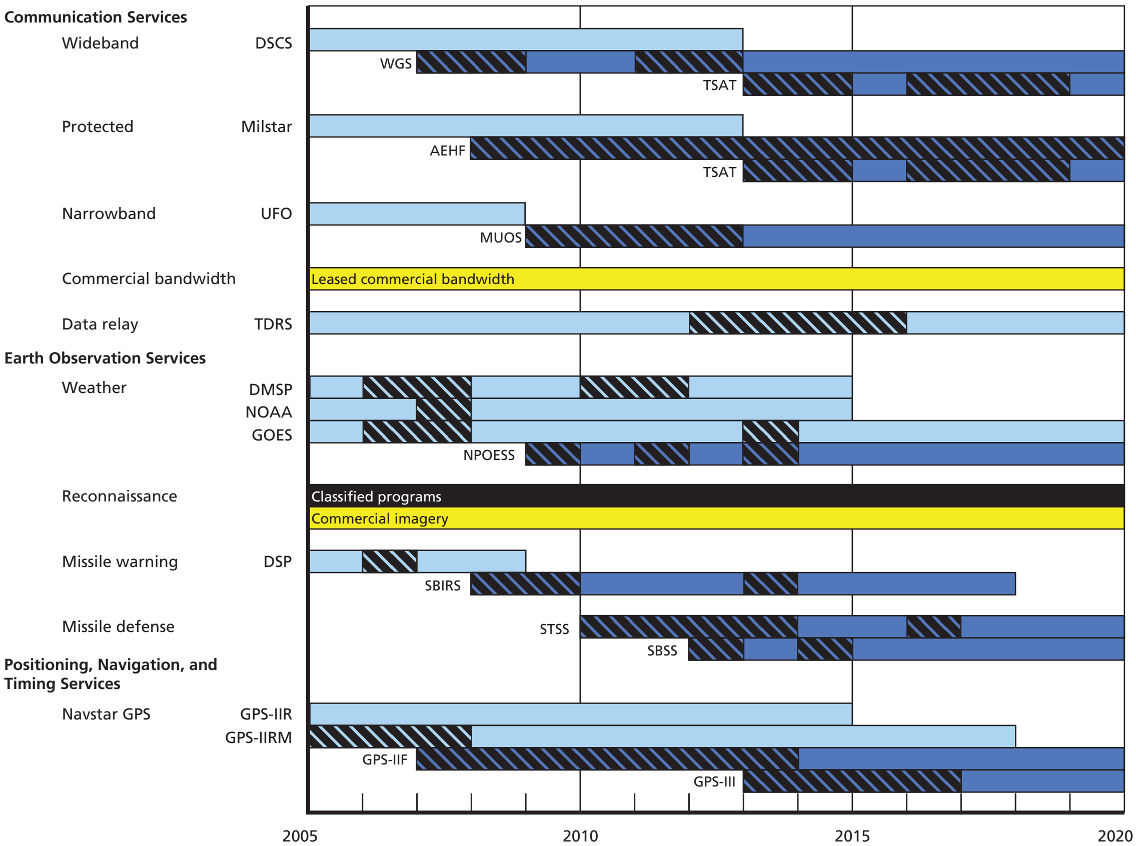
[4] Directorate of Space Acquisition (SAF/USA), "EELV Launch Schedule: FY06 PBR," November 29, 2005.

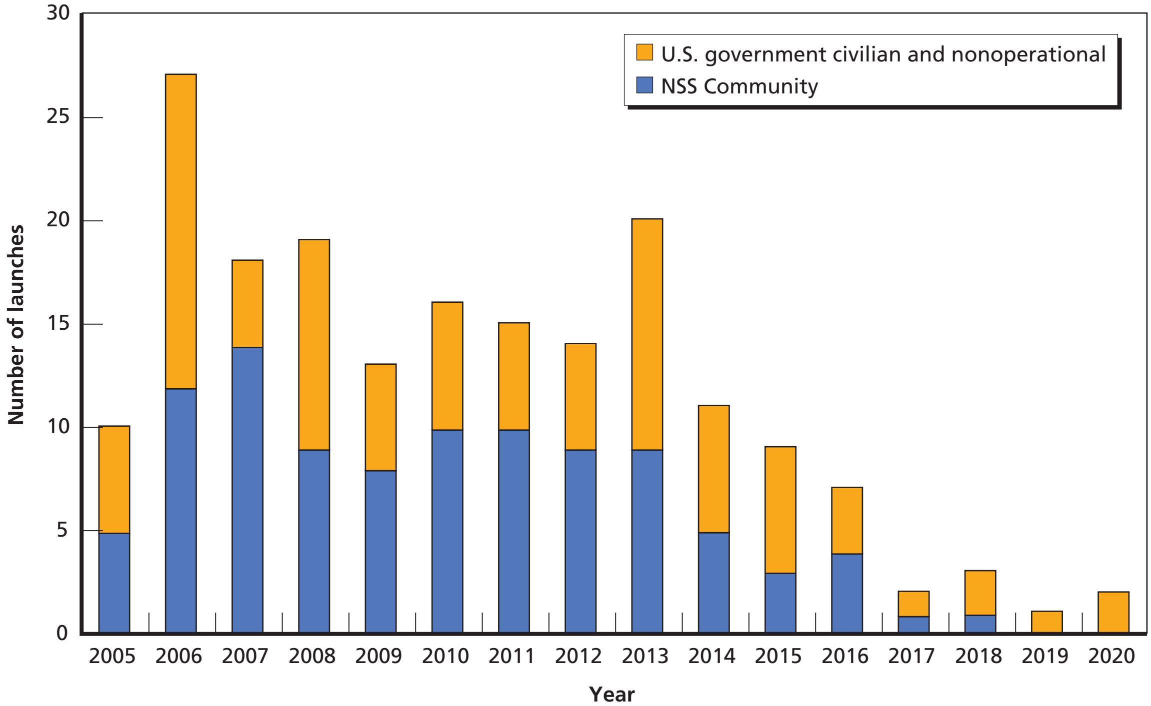
[5] New launch concepts are discussed at greater length in Chapters Five and Six of this report.

Figure 1.1
Legacy NSS Programs and Their Successors, Based on the Current Manifest



SOURCES: Directorate of Space Acquisition (SAF/USA), "EELV Launch Schedule: FY06 PBR," working paper, June 14, 2005; SAF/USA, "Jul–Sep 2005 Launch Forecast," working paper, July 5, 2005; "SAF/USA, "Eastern Range Launch Forecast: Jul 2005–Jun 2006," working paper, July 5, 2005; SAF/USA, "Western Range Launch Forecast, Jul 2005–Jun 2006," working paper, July 5, 2005; SAF/USA, "Delta/Atlas/Titan 14—Quarter Launch Forecast," working paper, July 5, 2005; SAF/USA, "Small Launch Vehicle/Ballistic/Shuttle 14—Quarter Launch Forecast," working paper, July 5, 2005; SAF/USA, "Appendix I: National Launch Forecast," from Buy III RFP Rev. 1, June 30, 2005; SAF/USA, "Delta/Atlas/Titan 14—Quarter Launch Forecast," working paper, July 11, 2005; SAF/USA, "Small Launch Vehicle/Ballistic/Shuttle 14—Quarter Launch Forecast," working paper, July 11, 2005; Boeing Launch Services, "Government EELV Manifest," briefing to the Panel, July 7, 2005; National Reconnaissance Office, Office of Space Launch, "NRO Launches (9/2005 thru 12/2015)," briefing to Panel, September 14, 2005; NASA, "NASA Launch Services Manifest," August 26, 2005; Headquarters U.S. Space Command/XORS, "National Launch Forecast (DRAFT)," September 12, 2005; Interviews, senior Air Force officials, October 26, 2005; Interviews, senior Air Force officials, November 7, 2005; Steven J. Isakowitz, Joshua B. Hopkins, and Joseph P. Hopkins, Jr., *International Reference Guide to Space Launch Systems*, 4th edition, Reston, Va.: American Institute of Aeronautics and Astronautics, July 2004; (SAF/USA, "EELV Launch Schedule: FY06 PBR," working paper, November 29, 2005; NASA, "NASA Launch Services Manifest," Revision 1, October 11, 2005; SAF/USA, "EELV Launch Schedule (USAF-NRO-NASA): FY07 PBR," working paper, March 6, 2006; Interviews, senior Air Force officials, March 16, 2006.
NOTES: This chart reflects the March 2006 Air Force mission manifest, not the schedule or annual launch rates discussed in this chapter. Cross-hatched years denote periods of planned satellite constellation replenishment. Program bars terminate when all current satellites have reached their design lifetime; some satellites may continue to operate beyond that date.
RAND *MG503-1.1*

Figure 1.2
The Current Manifest of All U.S. Government Launches from 2005 to 2020, by NSS and Non-NSS Missions



SOURCES: See the multiple sources listed in Figure 1.1.
NOTE: This chart reflects the March 2006 Air Force mission manifest, not the schedule or annual launch rates discussed in this chapter.
RAND *MG503-1.2*

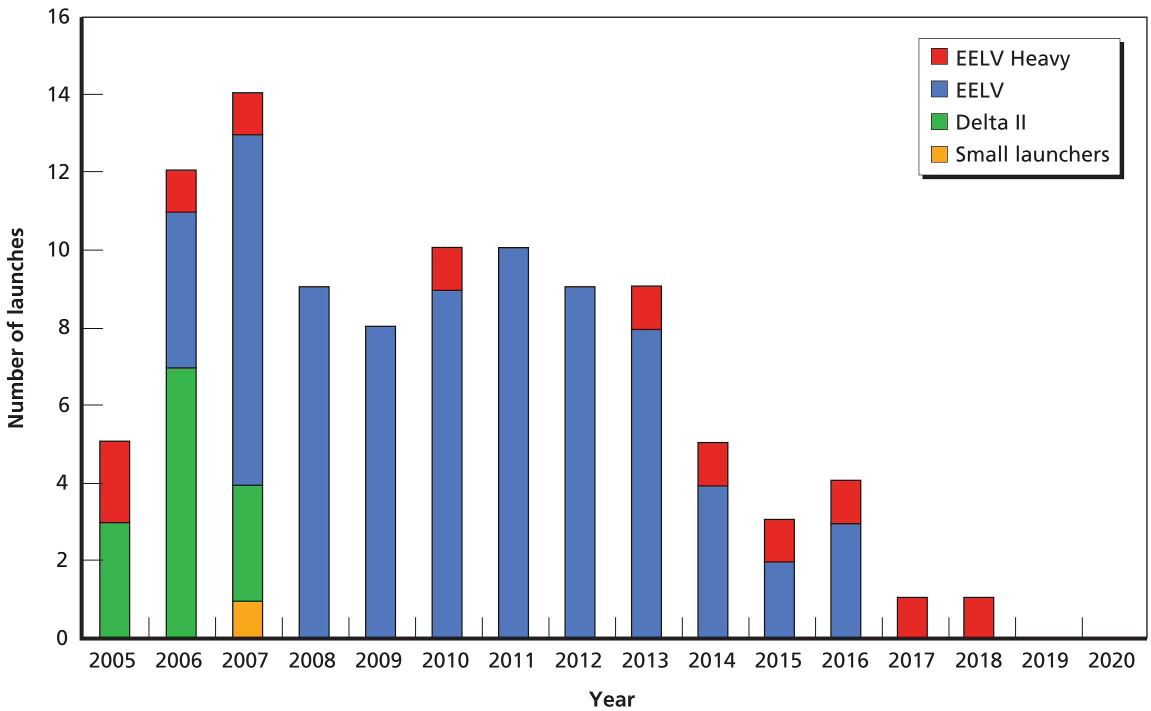
Assessing the Ability to Satisfy NSS Launch Requirements

As noted earlier, the two vehicles under the EELV program (the Delta IV and Atlas V) and the small vehicles (the Minotaur, Pegasus, and Taurus) constitute the U.S. domestic launch vehicle supply. In addition, some residual capacity still exists from previous generations of rockets: Delta II vehicles will be used to launch GPS satellites and other payloads through 2007.[6]

Based on the data presented in Chapter Three, it appears that the bulk of NSS launch requirements can be launched with either EELV family, although only the Delta IV Heavy has the performance to lift the ten NSS launch requirements that require a heavy-lift capability. Chapter Three also indicates that the production capacity for Atlas V is sufficient to satisfy the total projected demand for EELV intermediate launch vehicles and that the production capacity for Delta IV, with one possible exception, can satisfy the entire projected NSS launch

[6] Directorate of Space Acquisition (SAF/USA), "Delta/Atlas/Titan 14-Quarter Launch Forecast," July 5, 2005.

Figure 1.3
The Current Manifest of NSS Launches from 2005 to 2020, by Vehicle Class



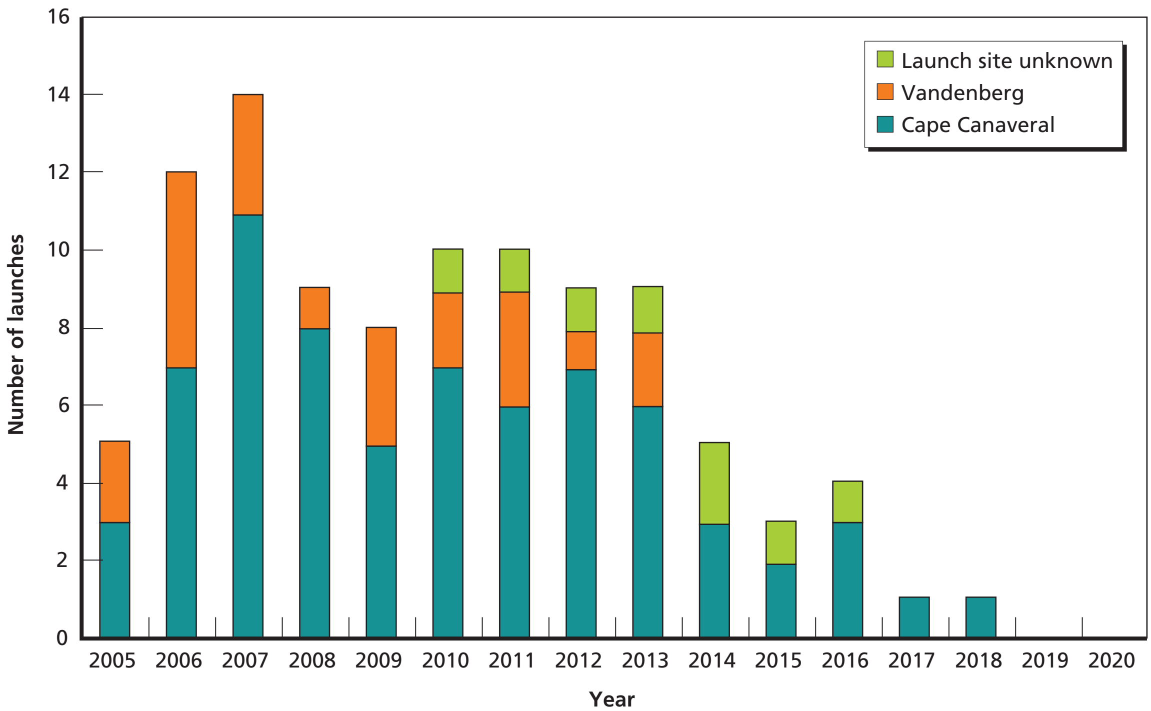
SOURCES: See the multiple sources listed in Figure 1.1.
NOTE: This chart reflects the March 2006 Air Force mission manifest, not the schedule or annual launch rates discussed in this chapter.
RAND *MG503-1.3*

demand. The exception involves the requirement to increase the Delta IV Heavy lift capability to accommodate a single NRO payload. The best solution to this requirement is currently under study.

Finally, Figure 1.4 shows that the demand for launches from Vandenberg Air Force Base (AFB) remains modest and, as discussed in Chapter Three, both the Eastern Range and the Western Range are anticipated to have sufficient capacity to accommodate the projected demand.

The conclusion is that the EELV program has the capacity to accommodate launch operations in excess of the projected demand through 2020.

Figure 1.4
The Current Manifest of NSS Launches from 2005 to 2020, by Launch Site



SOURCES: See the multiple sources listed in Figure 1.1.
NOTE: This chart reflects the March 2006 Air Force mission manifest, not the schedule or annual launch rates discussed in this chapter.
RAND *MG503-1.4*

Findings

1. Launch requirements are derived from space service requirements, but launch schedules are driven by spacecraft availability.
2. Each EELV family has the capability and production capacity to execute the entire projected NSS demand for single-core EELV launches through 2020.
3. Delta IV will have the capability and production capacity to execute all projected EELV heavy-lift requirements (with the possible exception of a single NRO payload) through 2020.

CHAPTER TWO

Payloads

Tasking

This chapter responds to specific tasking from House Resolution 4200: "The review and assessment shall take into account … payloads, including the implications of payloads for launch requirements."

Discussion

This chapter addresses relationships among satellites, launch vehicles, and NSS program decisions that affect launch requirements and the ability to satisfy them. A great deal of attention has been focused on maintaining assured access to space and, as discussed in Chapter One, maintaining assured NSS service. The following paragraphs discuss launch vehicle–payload interrelationships and illustrate the close collaboration required to ensure the continuity of space services and minimize total government cost.

Assured Access and Assured Service

Today, each NSS service program employs some form of a launch-on-schedule plan for payloads needed to deploy or maintain each constellation's required level of service. The execution of these plans requires setting an initial launch date and building payloads and launch vehicles in time to support that schedule. Then, depending on the health and capabilities of existing assets in space, the scheduled launch date may be deferred until the new payload's capabilities are required, or it may be accelerated to minimize service disruptions.

The EELV program is responsible for providing an operationally suitable launch vehicle when the satellite is ready (i.e., "assured access to space"). Because launch reliability is a paramount consideration, it is occasionally prudent to ground an entire family of launch vehicles when circumstances create uncertainty about the flight readiness of a launch vehicle configuration. At the time of grounding, the root cause for the concern and, therefore, the time necessary to restore service are generally unknown. Thus, the EELV program is maintaining two families of common-core vehicles to ensure that payload launch delays can be minimized in the event a payload's assigned vehicle is grounded.

The concept is straightforward: If a payload is integrated with both families, then it can be reassigned from one family to the other and launched as soon as the payload and launch vehicle can be mated. The Panel believes that this approach has direct application to the task of assuring service and notes that this strategy is currently being successfully employed in the commercial launch services arena. However, achieving such schedule assurance requires satisfying two conditions: (1) having a launch vehicle of the alternate family available and (2) having a satellite that has been completely integrated with both families before the scheduled launch date. This strategy can also be used to minimize service disruptions caused by launch failures or unanticipated failures of critical on-orbit assets, provided that replacement satellites and launch vehicles are available.

Executing the dual-integration strategy could be accomplished on common-core configurations with little cost to the EELV program because, as part of an ongoing production program, it requires building only one of each family ahead of schedule, not building a spare. The cost of dual integration to the payload program may, however, be significant for some designs. Accordingly, some payloads have elected to provide only design compatibility rather than bear the expense of completing detailed engineering integration on the alternate vehicle. This approach preserves the ability to shift launch vehicles at a future date but avoids what can be a very high, and probably unnecessary, expense for specialized payloads. It is also noteworthy that, today, payloads requiring a heavy-lift vehicle do not have this assured access option, since only the Delta family provides a heavy-lift configuration.

Satellites can fail; launch vehicles can fail; and launch vehicles can be grounded for protracted periods. The only way to confidently assure service is to provide reserve capacity on-orbit or timely access to a replacement satellite and launch vehicle. The two-family EELV concept intrinsically offers redundant launch capabilities to programs that can use the single common-core configurations and that find it attractive to have assets on the ground rather than provide reserve capacity on orbit.

Attractive as this aspect of assured access may appear, history suggests that the efficacy of this strategy should be reviewed as experience is gained. For example, a review of the past 20 years shows that only one of 14 failures resulted in a launch vehicle grounding that exceeded one year. In that case, a two-year delay resulted from satellite needs and availability, not launch vehicle readiness. Likewise, it appears that few satellite programs are currently planning to build spare vehicles. Therefore, the cost-effectiveness of maintaining two families for the sole purpose of providing redundant launch capabilities should be reviewed once confidence in the reliability and the cost of maintaining that reliability has been determined through operational experience.

Programmatic Interactions

Space programs are inherently expensive, and all satellite programs are striving to provide more capability or current capability at lower cost. As a result, spacecraft designs minimize the cost of sustaining service in several ways. Since both satellites and launch vehicles are expensive, it is often cost-effective to package as much capability as possible in a single, large satellite. In this case, the total cost of providing service is reduced by launching fewer, albeit more expensive, spacecraft on fewer, but higher-capacity, launch vehicles. Similarly, since the cost driver in most spacecraft is its payload, the increased cost of providing additional consumables to extend the satellite's service life is less than providing additional spacecraft to provide service over the extended period of time. Again, the additional cost of launching with a higher-capacity vehicle is generally less than the cost avoided by this strategy. Finally, the high cost of launch vehicles encourages some programs to reduce launch costs by co-manifesting multiple satellites on a single launch vehicle. These actions are all laudable and effective but have implications for launch and NSS service programs that warrant consideration.

Some NSS missions have satellite constellations that do not degrade or tolerate satellite outages gracefully. It is, therefore, important to launch these payloads when scheduled in order to maintain continued and assured service. These NSS missions are usually critical to national security, and continued service is a very high priority. These satellites tend to be very costly, "standby spares" are not readily available, and extended outages result from a failed launch. This situation results in extraordinary pressure to have 100-percent launch success when the launch is scheduled. As a result, the launch providers go to extraordinary efforts (at a relatively high cost) to achieve the desired 100-percent launch success. Despite heroic efforts, not all launches (manned or unmanned) are always successful. It is not reasonable to expect 100-percent launch success over an extended period of time. Painful as it may be, the satellite programs must accept the probability of less-than-100-percent launch success and plan accordingly. It is incumbent upon the launch community to strive mightily to achieve as near 100-percent launch success as possible. Hence, launch reliability is the most important goal of any launcher program.

Findings

1. Satellite programs must accept the probability of less-than-100-percent launch success and must plan accordingly.
2. The two-family EELV program has the inherent ability to contribute to assured space service following a launch failure or unanticipated on-orbit failure for programs that can utilize the single common-core configuration, provide a replacement spacecraft in a timely fashion, and integrate their payloads with both EELV families.
3. The EELV program, with two vehicle families, can minimize launch schedule disruptions for payloads that can utilize the EELV single common-core configuration, provided that the satellite has completed its integration with both families at the time of scheduled launch and that an alternate launch vehicle is available. Currently, not all NSS payloads are fully dual integrated.
4. The trends toward longer-life satellites, co-manifested payloads, and fewer and more capable satellites in a constellation reduce flight opportunities. This, in turn, increases the challenge of maintaining the level of proficiency needed to achieve the desired level of launch reliability.

CHAPTER THREE

Launch Infrastructure and Industrial Base

Tasking

This chapter responds to specific tasking from House Resolution 4200: "The review and assessment shall take into account … launch infrastructure [and] launch industrial base."

For the purposes of this study, we defined launch infrastructure and industrial base as follows:

- Launch vehicles and associated manufacturing and base operating facilities, such as launchpads, vehicle processing buildings, and storage structures
- Satellite processing facilities at or near the launch site
- Range support equipment, such as radars, telemetry, communications, and down-range assets.

Discussion

To obtain the information required for this analysis, the Panel contacted the government agencies and contractors involved in manufacturing launch vehicles and associated hardware, in processing and launching vehicle hardware, and in operating ranges. The intent was to determine whether current and projected improved capabilities can meet the expected NSS launch requirements, taking into account all the other activities demanded of the launch vehicles and launch ranges for the period from 2005 to 2020.

Launch Vehicles, Manufacturing, and Assembly

U.S. launch policy has historically mandated that NSS payloads be launched on domestic launch vehicles. This has been policy since the Carter administration and has continued to appear in every major policy directive, including the most recent National Space Transportation Policy (NSTP). The current domestic launch capabilities consist of two vehicle families developed under the EELV program (the Delta IV and Atlas V) and a number of small vehicles (the Minotaur, Pegasus, and Taurus). In addition, some residual capacity remains from previous generations of rockets, such as the Delta II, which is still used for GPS and other payloads but primarily for NASA scientific payloads. For the purposes of this analysis, we concentrated on the EELV and Delta II programs because they are the primary U.S. NSS launch vehicles used today and in the foreseeable future. For the sake of consistency, we have categorized launch vehicles as follows:

- Small (Pegasus, Minotaur, and Taurus)
- Medium (Delta II)
- EELV (all Atlas V and Delta IV configurations that use a single common core)
- EELV Heavy (three common cores). (A heavy-lift Atlas V variant has been designed but not developed.)[1]

Lockheed Martin builds the Atlas V, and Boeing manufactures the Delta II and Delta IV. The Atlas V and the Delta IV, developed under the Air Force EELV program, had their initial flights in 2002. To date, all flights of the different EELV family variants have been successful. Even though the Delta IV Heavy did not attain the intended orbit in a demonstration launch, it did demonstrate the operation and performance of the hardware and software components.

Atlas V. The Atlas V launch vehicle system is based on the 3.8-meter-diameter (12.5-foot-diameter) CCB powered by a single Russian RD-180 engine. The RD-180 uses liquid oxygen and liquid hydrocarbons (a highly refined grade of kerosene) for propellant. The Atlas V 400 series combines the CCB with a standard 4-meter-diameter Atlas payload fairing. The Atlas V 500 series combines the CCB with a larger 5-meter fairing. The Atlas V 400 and 500 series can tailor their performance by incorporating up to five solid strap-on rocket boosters. Both the Atlas V 400 and 500 configurations incorporate a Centaur upper stage configured with one or two RL-10 engines. The RL-10 uses liquid oxygen and liquid hydrogen for propellant.

Figure 3.1 shows the Atlas V family of launchers, and Figure 3.2 provides the family's payload lift capabilities. A three-digit naming convention was developed for the Atlas V to identify its multiple configurations: the first digit identifies the payload fairing diameter (4 or 5 meters); the second digit indicates the number of strap-on solid rocket motors (0 to 5); and the third digit denotes the number of Centaur engines (1 or 2). As an example, the Atlas V 531 would be configured with a 5-meter payload fairing, three strap-on solid rocket motors, and a single-engine Centaur.

The Atlas V is currently manufactured at a facility near Denver, Colorado (see Figure 3.3.). The vehicle tank is fabricated in a modern facility using state-of-the-art automated welding and testing techniques and is then assembled with the Russian RD-180 engine. Lockheed Martin has made major efforts to demonstrate that its U.S. engine subcontractor, Pratt & Whitney Rocketdyne, understands the production technology for the RD-180 engine and could coproduce the engine if required. From the data presented to the Panel, we conclude that the documentation is in hand and that the production techniques are understood. The next step proposed by Lockheed Martin is to develop critical components of the engine and incorporate them into an RD-180 produced in Russia for testing.

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[1] Discussions with Lockheed Martin and International Launch Services, June and September 2005.

Figure 3.1
Atlas V EELV Family

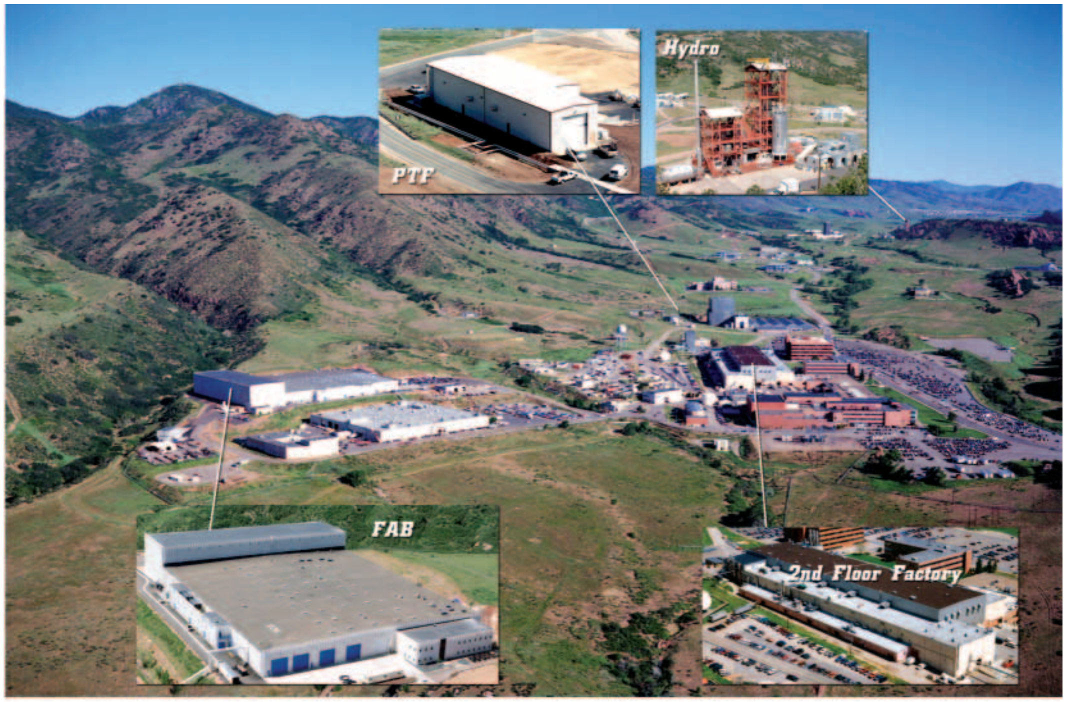
SOURCE: Used with permission of Lockheed Martin.

Figure 3.2
Atlas V Kilogram Mass-to-Orbit Capabilities

Orbit[a] Configuration	LEO 185 x 185 km orbit 28.5 degrees inclination	LEO Polar 185 x 185 km 90 degrees	ISS 407 x 407 km 51.6 degrees	SSO 800 x 800 km 98.6 degrees	GPS 20,200 x 20,200 km 55.0 degrees	GEO Transfer 167 x 35,788 km 27.0 degrees	GEO 35,788 x 35,788 km 0.0 degrees
–401	9,050[b]	7,335	8,460	6,670	2,450	4,950	N/A
–411	9,050[b]	9,015	9,050[b]	8,495		6,075	N/A
–421	9,050[b]	9,050[b]	9,050[b]	9,050[b]		7,000	N/A
–431	9,050[b]	9,050[b]	9,050[b]	9,050[b]		7,800	N/A
–501	8,250	6,420	7,190	5,945		3,970	N/A
–511	10,950	8,560	9,050	7,820		5,370	N/A
–521	13,300	10,490	11,080	9,585		6,485	2,760
–531	15,300	12,185	12,810	11,160		7,425	3,255
–541	17,100	13,480	15,400	12,435		8,240	3,730
–542	18,955	14,800	16,990				
–551	18,500	14,520	16,600	13,550	5,000	8,700	3,960
–552	19,050[b]	16,125	19,050[b]	14,490			

[a] LEO Polar and sun-synchronous capabilities are measured from Vandenberg AFB. All other capabilities are measured from Cape Canaveral Air Force Station (AFS).
[b] These figures represent the vehicle's structural limit without additional analysis or modification, not the performance limit.
SOURCES: Data provided by International Launch Services. Interview with Lockheed Martin Space Systems official, February 9, 2006.
NOTE: The lift capabilities of the Atlas V 4xx to low earth orbit (LEO) and sun-synchronous orbit (SSO) are limited by the structural capacity of ground handling equipment and the Centaur booster. These limitations can be overcome by employing the larger payload fairing of the 5xx series for high-mass launches to these orbits.
RAND *MG503-3.2*

Figure 3.3
Atlas V Manufacturing Facilities in Denver, Colorado



SOURCE: Used with permission of Lockheed Martin.

The Centaur is the upper stage for the Atlas V and is manufactured near San Diego, California. It is subsequently sent to the Denver facility for final assembly and mating with a version of the Pratt & Whitney Rocketdyne RL-10 upper-stage engine. The RL-10 has been in production for many years and meets all currently known and projected requirements. A different version of the RL-10 engine is also used in the Delta IV upper stage. The use of the RL-10 in both the Atlas V and Delta IV vehicles has been raised as a potentially troubling source of a single-point failure. There are differences in the capabilities of the two RL-10 variants (e.g., the Delta IV version provides more thrust from the engine than the Atlas V version does). Regardless, they do represent a common component in the two systems. A failure that affects the RL-10 and grounds the Atlas and Delta EELVs could potentially hinder the United States' ability to implement current national policy regarding assuring access to space.

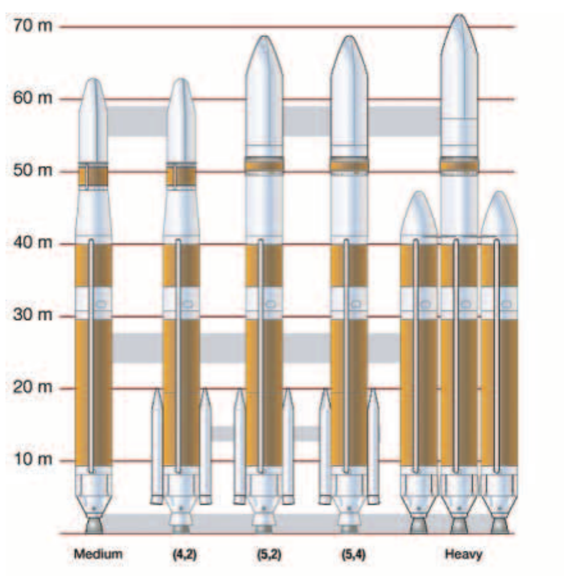
Pratt & Whitney Rocketdyne has adequate manufacturing capacity to meet the engine needs of the Atlas V and the Delta IV programs. The EELV companies have procured the RL-10 differently. Boeing chose to buy enough engines to provide support through approximately 2011, while Lockheed Martin buys the RL-10 on a deliver-as-needed basis. In both cases, the availability of the RL-10 is not an issue for the Delta IV or Atlas V programs. As noted above, the primary concern in this regard is related to a potential failure of one version that might cause a stand-down for both versions.

The Aerojet Corporation, based in Sacramento, California, manufactures the strap-on solid rocket motors that provide additional lift capability for the Atlas V. Aerojet upgraded its capacity to produce these motors in sufficient quantity when Lockheed Martin selected Aerojet as the supplier of this hardware. Once produced, the motors are shipped overland by specially designed canisters to the respective launch base. The Atlas V 551, with a full complement of five solid rocket motors, was successfully flown in January 2006.

The Atlas V's Denver-based manufacturing facilities have been in existence for years and were used for previous versions of the Atlas and Centaur. These facilities were upgraded by the EELV program. There are no plans to further upgrade either the Denver or the San Diego facilities. With approval of the creation of the United Launch Alliance (ULA), the production capacity will be moved to the Decatur, Alabama, production complex. The Panel believes that the Atlas V manufacturing facilities with existing tooling can satisfy all known and projected production requirements through 2020.

Delta IV. The Delta IV is based on a CBC powered by a single, liquid oxygen-hydrogen, pump-fed RS-68 engine. There are several variants of the Delta IV. The Delta IV Medium (which replaces the Delta II) uses a CBC with a standard Delta II second stage and a 4-meter payload fairing. There are three versions of the "intermediate" Delta IV. The Delta IV M+(4, 2) combines the CBC with two strap-on solid rocket motors, an upper stage, and a 4-meter payload fairing. The Delta IV M+(5, 2) combines the CBC, two strap-on solid rocket motors, an upper stage, and a 5-meter payload fairing. The Delta IV M+(5, 4) combines the CBC with four strap-on solid rocket motors, a larger upper stage, and a 5-meter payload fairing. The Delta IV Heavy combines three CBCs with a larger upper stage and a 5-meter payload fairing. Figure 3.4 shows the Delta IV family, and Figure 3.5 provides the family's payload lift capabilities.

Figure 3.4
The Delta IV EELV Family



SOURCE: Used with permission of The Boeing Company.

Figure 3.5
Delta IV Kilogram Mass-to-Orbit Capabilities

Orbit[a] / Configuration	LEO 407x407 km orbit 28.7 degrees	LEO Polar 407x407 km 90 degrees	ISS 407x407 km 51.6 degrees	SSO 834x834 km 98.7 degrees	GPS 20,368x20,368 km 55.0 degrees	GEO Transfer 185x35,786 km 27.0 degrees	GEO 35,786x35,786 km 0.0 degrees
M	9,150	7,510	8,570	6,850	1,750	4,300	1,110
M+ (4,2)	12,240	10,200	11,680	9,350	2,750	6,030	1,970
M+ (5,2)	10,640	8,680	10,160	7,910	2,400	5,020	1,690
M+ (5,4)	13,360	11,300	13,030	10,400	3,640	7,020	2,700
Heavy	22,560	21,140	22,560	19,420	7,570	12,980	6,160

[a]LEO Polar and sun-synchronous capabilities are measured from Vandenberg AFB. All other capabilities are measured from Cape Canaveral AFS.
SOURCES: Data provided by Boeing Launch Services. Interview with Lockheed Martin Space Systems official, February 9, 2006.
NOTE: The M and M+ nomenclature is used by Boeing Launch Services and is different from the terminology used by the Panel.
RAND *MG503-3.5*

The Delta IV is manufactured in Decatur, Alabama, at the most modern facility in the U.S. space industry (see Figure 3.6). This manufacturing facility was constructed as part of the EELV program with a planned production capacity of 40 CBCs a year. Presently, it is equipped to accommodate production of approximately 20 cores a year, a capacity that meets all known and projected requirements. All Delta IV major assembly activities are performed at the Decatur facility, including the addition of electrical and mechanical components. Following assembly and checkout, the vehicle is shipped to either the Eastern or Western Range for final processing and launch. The vehicle is too large for road transport and is delivered to the launch site by a specially designed ship.

Boeing and Pratt & Whitney Rocketdyne developed the RS-68, a new liquid oxygen and hydrogen engine, to power the Delta IV. It is the first new liquid engine developed in the United States since the Space Shuttle Main Engine (SSME). The engine is produced at the Pratt & Whitney Rocketdyne plant in California, which has the production capacity to meet all foreseen needs. To date, the engines have performed without a problem. The U.S. Air Force is considering upgrading the engine to increase its thrust for heavier payloads.[2]

Alliant Techsystems Inc., in Utah, builds the strap-on solid rocket motors for the Delta IV. The Alliant Techsystems manufacturing facilities can produce adequate quantities of motors to satisfy all projected future needs. The motors are shipped via overland transport to the respective launch base as required to support launch demands. To date, all the motors launched have performed satisfactorily.

Delta II. The Delta II, a variant of the Delta heritage launch vehicle program, was developed in the 1980s under the Medium Launch Vehicle II acquisition. DoD has used the vehicle since 1988 to launch GPS satellites, and it is the primary launch vehicle for NASA science mis-

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[2] During the spring of 2006, NASA decided to use the RS-68 as the first-stage liquid engines for the planned heavy-lift Cargo-Launch Vehicle (CaLV) versus a modified version of the SSME. See Frank Morring, Jr., "Money Talks, Costs Driving NASA's Decision on Exploration Architecture; Shuttle Heritage Losing Emphasis," *Aviation Week Space & Technology*, May 29, 2006.

Figure 3.6
Delta IV Assembly Facility in Decatur, Alabama

SOURCE: Used with permission of The Boeing Company.

sions. DoD has announced plans to phase out its use of the Delta II in favor of using the EELV. NASA is considering using the EELV for science missions; however, there is no agreement at present regarding when and how such a transition to the EELV might occur. Given the analysis conducted by the Air Force and NASA, it is unlikely to occur until about 2009, when the current buy of Delta II launch vehicles is expended.[3] The inventory of liquid propellant engines for the Delta II has been delivered to satisfy these requirements, and the production capacity is in a standby mode.

Production of the Delta II was recently moved to the Decatur facility. The production rate will meet all DoD and NASA requirements in the time period of interest. The Delta II and Delta IV have separate production lines and do not interfere with each other in the production process. No major improvements or changes are anticipated or required to maintain this production capability. The Delta II has three launchpads: Space Launch Complex (SLC)–17A and SLC-17B at the Eastern Range and SLC-2 at the Western Range. All three are fully operational and well maintained. Both locations have adequate vehicle processing and satellite processing facilities to support Delta II operations. At Cape Canaveral AFS and Vandenberg AFB, several off-pad facilities are used to store the vehicle components and to prepare the launch vehicle before actual transport to the pad. All these facilities meet the needs for processing and launch rate.

The solid rocket motors used to provide the Delta II with additional lift capability are produced by Alliant Techsystems. All vehicle components can be transported overland, and storage capacity exists at each site for several Delta II vehicles. Personnel for the Delta II are shared between the East and West Coast launch sites.

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[3] Discussions with SAF/USA and Boeing officials, June and September 2005.

Small Launch Vehicles

The current U.S. capability for small space launch vehicles comprises the Minotaur, Taurus, and Pegasus vehicles, all of which are built and operated by Orbital Sciences Corporation. The U.S. government uses these vehicles extensively, particularly for DoD R&D payloads. All three vehicles use solid propellant, and both the Minotaur and Pegasus can accommodate a rate of four to six launches per year, with 600- and 450-kilogram payload capacities to LEO, respectively; the Taurus, in comparison, can lift 1,375 kilograms. The vehicles, developed in the 1990s under the Defense Advance Research Project Agency's (DARPA's) Small Space Launch Vehicle program, are quite versatile. The Taurus and Minotaur require minimal ground infrastructure and can be launched from a number of sites worldwide; the Pegasus, air-dropped from an L-1011 aircraft, can be launched from any site that will accommodate the aircraft. Taken together, the family of launch vehicles developed by Orbital Sciences represents all the current U.S. operational capability for small launch vehicles.[4]

United Launch Alliance

Lockheed Martin and Boeing have proposed ULA as a joint venture to consolidate the management, manufacturing, assembly, and launch operations of the Atlas V and Delta IV vehicles. The venture will also have the responsibility for the heritage Delta II system. All vehicle production (Atlas V, Delta IV, Delta II, and Centaur) would be relocated to Decatur, Alabama. This facility, as noted earlier, was sized to produce 40 vehicles a year. The Panel believes that the facility can accommodate production of both EELV families and the Delta II at the rate required to support the known and projected manifests. Lockheed Martin and Boeing have submitted a proposal to the U.S. government and, at the writing of this report, are awaiting approval from the Federal Trade Commission (FTC) and other government entities to establish ULA. The companies state that cost savings can be realized three years from the start of transition and approval. Some initial additional investment will be required to move equipment and people. These costs and other issues are part of ongoing discussions between the Air Force, DoD, and the FTC.

Launch Processing

Atlas V. Following production and factory checkout, the Atlas V is shipped to the launch site by air transport (see Figure 3.7). The solid motors are transported overland to the launch site. The systems are further checked out and prepared for launch at the launch base. The Atlas V is processed at the Eastern Range in two primary buildings: the Atlas Space Operations Center (ASOC) and the Vertical Integration Facility (VIF) (see Figure 3.8, left). The ASOC is used for electrical and integrated tests prior to movement to the VIF, where the vehicle is erected on the transporter.

Eastern Range launch operations are conducted from the SLC-41, which employs a "clean pad" concept that requires very little pad infrastructure (see Figure 3.8, right). The Atlas V has proved capable of launching within eight hours of arrival at the launchpad and also has dem-

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[4] All Small Launch Vehicle information taken from Orbital Sciences Corporation, "Orbital Sciences Corporation's Launch Vehicle and Satellite Outlook," briefing to the Panel, September 13, 2005.

Figure 3.7
Atlas V Air Transport and Launch Control Center

SOURCE: *Top and bottom*, used with permission of Lockheed Martin.

onstrated a 24-hour recycle time after a launch attempt scrub. SLC-41 has been sized and engineered to accept a heavy-lift variant should such a variant be developed. Additional development and construction resources would be needed to attain this capability. The state-of-the-art Atlas V facilities, built as part of the EELV program, are capable of processing and launching approximately 20 vehicles each year. Additional processing facilities, such as the VIF, would be needed to increase this launch capacity significantly.

On the Western Range, the Atlas V uses a different concept of operations. The vehicle is stacked on the pad at SLC-3E, a facility modified from an Atlas II configuration to accommodate the Atlas V. The initial launch from this facility is expected in early 2007. The West Coast facility is limited to an Atlas V 55x variant and is not capable of launching a heavy-lift Atlas V variant. The maximum launch rate at the Western Range is approximately three per year.

The launch site cadre for the Atlas V is sized to meet the current production and launch rate of vehicles ordered and manifested by the Air Force, NASA, and the commercial sector. The size of the cadre represents a major reduction compared with heritage launch programs. Launch processing personnel support launch base activities on both the Eastern and Western

Figure 3.8
Atlas V East Coast Vertical Integration Facility and the SLC-41

SOURCE: *Right and left*, used with permission of Lockheed Martin.

ranges and work under a one-team concept. They will use, as far as practical, common procedures and processes and will be commonly managed. The common management produces cost savings from cross-use of engineering and technical personnel.

Delta IV. The Delta IV is transported to both East and West Coast ranges by ship. Upon arrival at either facility, the launcher is moved to a Horizontal Integration Facility for final electrical checks and assembly. The Delta IV is transported via a specially developed wheeled transporter. Final launch processing, including installation of the strap-on solid rocket motors, the upper stage, and the payload fairing and satellite, is accomplished on the launchpad. The launch preparation process was designed to require eight days, but that has yet to be achieved for a number of reasons (many unassociated with the launch vehicle itself or delays of the availability of the payload). Launch operations are conducted from SLC-37 on the Eastern Range (see Figure 3.9) and SLC-6 on the Western Range. All launches to date have been from SLC-37 on the Eastern Range. The initial launch from SLC-6 on the Western Range occurred in June 2006. All variants of the Delta IV, including heavy lift, can be launched from either SLC-37 or SLC-6. SLC-37 is a new pad specifically designed for the Delta IV family. SLC-6 was formerly the planned Shuttle launchpad and was modified to accommodate the Delta IV. Both coasts have a "traditional" launchpad with major mobile service and umbilical towers. The pad also has major power and associated underground facilities for electrical checkout and erecting the launcher. The strap-on solid rocket motors are attached to the CBC on the pad.

Figure 3.9
Delta IV East Coast Launchpad (SLC-37)

SOURCE: Used with permission of The Boeing Company.

As is the case with the Atlas V, the Delta IV processing and launch cadre will be shared between the Eastern and Western range launch sites. The personnel requirements for the Delta IV are significantly reduced when compared with the heritage systems workforce.

Satellite Processing Facilities

The Panel did not evaluate in detail the satellite processing facilities at the two launch locations. However, in the government's judgment, the upgraded and modernized facilities will be adequate to support the known and projected requirements.[5] The Panel concurs with this assessment.

Launch Ranges

The national launch ranges supporting NSS mission requirements are the Eastern Range located at Cape Canaveral AFS and the Western Range located at Vandenberg AFB. These ranges have maintained a commendable record for launch and test support, despite the advancing age of the equipment and facilities. There has been a modest and continuing level of funding for range modernization and sustainment of range assets over the years. As a whole, the

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[5] Interviews, NRO officials, December 2005.

ranges remain fully operable, although the current status of range equipment and facilities varies by capability.

According to Air Force range data, launch scrubs or recycles attributed to range failures have historically been less than 1 percent of all occurrences. One of the reasons range failures affecting launch have been infrequent is the high degree of backup. For example, three radars might be maintained to be sure one is available at the time of launch. These additional radars mitigate such issues as tracking problems resulting from flame attenuation or vehicle events. When these problems cause range systems to lose the ability to track the vehicle or provide telemetry, the alternate sources fill in the data needs. Such backup, however, can obscure reliability issues and add operations and maintenance (O&M) costs to the additional systems. The trade-off between new equipment and/or maintenance and spares for existing systems is always an issue range operators and program managers must address.

After reviewing the budget and the plans for upgrading and improving the Eastern and Western ranges, the Panel concludes that the ranges are capable of supporting all known and projected EELV launch requirements. Figure 3.10 provides a strong indication of the Air Force's ongoing commitment to operating and maintaining the ranges. In August 2003, the Air Force reprioritized completion of several ongoing range standardization and automation efforts. This has resulted in the delivery of a significant amount of modernized equipment to the ranges. The Air Force budget for range modernization and recapitalization for FY 1996 through FY 2005 totaled $1.475 billion, while O&M funding totaled $2.503 billion during the same period. In comparison, the Air Force plans to spend $840 million on range modernization and recapitalization from FY 2006 to FY 2011 (a 5-percent average annual decrease), while O&M funding would total $2.144 billion during the same period (a 43-percent average annual increase). This overall increase in funding (up 25 percent annually) suggests that support for the ranges will remain robust in the coming years. This is particularly clear when taking into account the recent increase in modernization and recapitalization (up 43 percent from FY 2004 to FY 2006) to address emerging requirements. The modernized equipment being delivered includes systems to expand planning and scheduling, communications, digital telemetry, weather, and flight safety capabilities.

Figure 3.10
U.S. Air Force Range Budget (in millions)

	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11
RDT&E	$ 48	$ 34	$ 36	$ 28	$ 48	$ 57	$ 66	$ 85	$ 59	$ 46	$ 49	$ 38	$ 27	$ 12	$ 10	$ 10
OPAF	110	99	75	91	83	95	127	106	80	102	114	122	143	104	106	107
O&M	246	249	227	214	224	236	239	260	295	312	349	344	351	359	367	375
Total	**$404**	**$382**	**$338**	**$333**	**$356**	**$388**	**$432**	**$451**	**$434**	**$ 460**	**$512**	**$503**	**$520**	**$475**	**$482**	**$ 492**
FY 96–05 Total RDT&E/OPAF										**$1,475**						
FY 96–05 Total O&M										**$2,503**						
FY 06–11 Total RDT&E/OPAF																**$ 840**
FY 06–11 Total O&M																**$2,144**

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The Panel believes that the funding and improvement programs planned for the ranges are reasonably balanced with the demands placed on this infrastructure. This situation must be watched carefully to ensure that critical resources are not reduced to the detriment of NSS missions.[6]

Findings

1. The EELV families can accommodate known NSS requirements.
2. The Atlas V and the Delta IV EELV programs have developed modern, state-of-the-art manufacturing, processing, and launch facilities. These facilities can support the known and projected NSS launch requirements through 2020. Continued U.S. government infrastructure funding will be required to adequately maintain these capabilities and facilities.
3. There are no major issues that lead the Panel to believe that the ranges cannot support the launch rate projected through the period of interest. Current and projected funding appears to be adequate, and the planned improvement programs should be continued.
4. The existing industrial base and workforce for sustaining Atlas V and Delta IV production and operations appear adequate to support NSS launch needs through 2020.

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[6] The potential demands placed on the ranges by Operationally Responsive Space (ORS) are not defined well enough to make judgments regarding their potential effect on range requirements (see Chapter Five). Regardless, the Panel believes that there is adequate time to make adjustments, as necessary, to meet an increase in launch tempo resulting from possible ORS needs. The ORS range needs are too vague in definition and in concept at this point to be considered a major driver for new range capabilities.

CHAPTER FOUR

Space Launch Economics

Tasking

This chapter responds to specific tasking from House Resolution 4200: "The review and assessment shall take into account … launch economics."

Discussion

Overview of Launch Economics

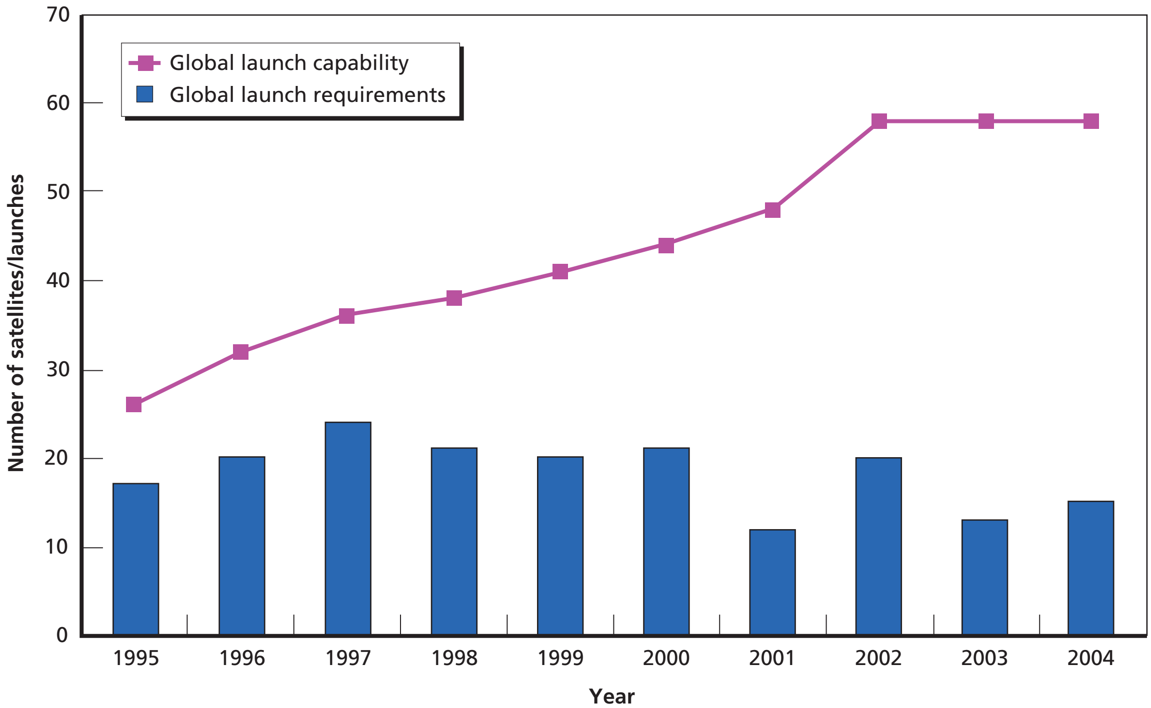
The Panel analyzed launch economics within the broader context of an entire end-to-end capability rather than focusing solely on the costs and prices associated with a single launch, given that the key objective of the EELV program was to provide an end-to-end national expendable launch capability. The EELV program was initially structured as a commercial acquisition for which the government did not require the use of detailed government cost accounting methodologies. Accordingly, verifiable launch and total system cost data were not readily available. It was also difficult to obtain verifiable cost data on commercial and foreign-developed launch capabilities.

Launch economics cannot be assessed within the classic economic model of supply and demand. Launch economics are primarily shaped by the demand for the capability and ensuring that base costs are as low as possible. There is and will continue to be over the next 15 years a worldwide oversupply of launch capability. Global demand for commercial geosynchronous earth orbit (GEO) satellite launch services from 2005 to 2015 is forecast to remain between 15 and 20 launches per year (see Figure 4.1). It is estimated that the global capacity will approach 60 launches per year. As commercial GEO satellites become more capable, and fewer but larger and more expensive constellations are built, this means that fewer satellites will be built for the constellations. The Panel believes that the EELV launch family will not capture a significant commercial business base without U.S. government intervention.

EELV Program Acquisition Strategy

The EELV program was initiated in 1995 to replace multiple legacy expendable launch vehicles with a system of greater operational flexibility and lower costs. The program's principal goal was to significantly reduce recurring production and launch costs. The development of this new launch

Figure 4.1
Global Capability and Requirements of Launch Vehicles for Geosynchronous Communications Satellites, 1995–2004



SOURCE: David Cavossa, Satellite Industries Association, "'State of the Satellite Industry' Report," briefing to the Panel, September 14, 2005.
RAND *MG503-4.1*

capability was estimated to cost the government approximately $1.5 billion.[1] The key to the government's cost savings estimates was the belief that the number of EELV launches would increase substantially between 2002 and 2020 (the 2011 to 2020 numbers were extrapolations), arising from the emergence of a robust commercial satellite market that would "pay" for most of the EELV's fixed costs. The government would be the secondary user. The government estimated that between FY 2002 and FY 2020 there should be a total of 181 launches (later reduced to 137 launches), as a subtotal that would have been NSS launches.[2] Therefore, recurring production and launch costs could be reduced substantially compared with the current legacy systems by consolidating to a modern single family of vehicles and supporting infrastructure.

The EELV program development was initially to have been government funded, but the potential for large commercial sales prompted the competing contractors (Boeing and

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[1] General Accounting Office (now the Government Accountability Office), *Evolved Expendable Launch Vehicle: DoD Guidance Needed to Protect Government's Interests*, Washington, D.C., GAO/NSIAD-98-151, June 1998, p. 14.

[2] Government Accountability Office, *Defense Space Activities: Continuation of Evolved Expendable Launch Vehicle Program's Progress to Date Subject to Some Uncertainty*, Washington, D.C., GAO-04-778R, June 2004, p. 3.

Lockheed Martin) to also invest their own resources. The U.S. Air Force devised a military-commercial acquisition strategy in which commercial market demands would provide sufficient funding to pay for and sustain a reliable state-of-the-art launch capability, with the government buying approximately one-third of the launches. The U.S. government invested a total of $1 billion ($500 million in each contractor development activity) to develop the EELV families. The underlying assumption was that the commercial market would be sufficiently robust to support two launch providers. It was reported to the Panel that Lockheed Martin invested $1.6 billion and Boeing invested $2.3 billion in their respective systems and associated infrastructures (a portion of which was written off by each company as "losses against profit"). Some of the investment was provided through allowable independent research and development. The estimated total development program costs were approximately $5 billion (U.S. government and industry).

By 2002–2003, the failure of the commercial market to materialize, compounded by an oversupply of global launch capability, led the Air Force to revise the acquisition strategy to a government-supported program. With the development of two families of vehicles approaching completion, the government reasoned that two families of vehicles provided the redundancy needed for "assured access to space," a concept discussed in Chapter Two. An acquisition strategy was developed that would reduce risks by requiring a mutual backup capability resulting in two independent but complementary U.S. manufactured[3] launch capabilities, thereby reemphasizing the importance of not only the system but also the overall capability's reliability.[4]

In 2004, the Secretary of Defense, as required by law, recertified the program with Congress. He argued in the recertification that the EELV was critical to national security and that, hence, the increased cost estimates were reasonable. The total program costs are now estimated to be approximately $32 billion through 2020. This figure includes all Air Force and NRO funds but excludes any NASA funds.[5]

The "Buy" Strategy

The EELV acquisition strategy, revised again in March 2005, focuses on retaining a modern launch infrastructure and critical workforce skills to manage reliability and cost risks that could emerge with an underutilized launch capacity. Four incremental and overlapping "buys" are planned. The initial "Buy 1," implemented in 1998, was structured on a firm-fixed-price contract in anticipation of a large commercial demand. It originally consisted of 19 launches allocated to Boeing and nine to Lockheed Martin. Later, two launches were reallocated to Boeing when Lockheed Martin decided not to develop an Atlas V heavy-lift vehicle or to build a West Coast launch facility. In addition, Boeing received exclusive rights to the West Coast launch facility for all launches as well as $150 million for a demonstration launch of the Delta IV Heavy variant. The subsequent Procurement Integrity Act (PIA) findings against Boeing

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[3] The U.S. government determined that critical to assured access was that foreign sources for launch in accordance with FAR 6.302-7 be excluded from providing launch services. In addition, potential sources for launch were restricted to Lockheed Martin and Boeing.

[4] GAO (2004), p. 3.

[5] Interviews, senior Air Force officials, December 5, 2005.

resulted in seven launches being reallocated to Lockheed Martin (resulting in each contractor having 14 launches in the Buy 1 program) and the approval for construction of an Atlas V West Coast launch facility. Two of the total 28 launches were later canceled, leaving a total of 26 Buy 1 launches.[6]

"Buy 2" consisted of one mission to Boeing and five missions to Lockheed Martin beginning in FY 2002 and concluding in FY 2011.[7] The Buy 1 and Buy 2 costs included all infrastructure costs. Buy 2, funded primarily by the NRO, focused on buying a total launch service, especially with the Atlas family of vehicles. Therefore, the scope of the buys varies, and, accordingly, the vehicle prices for each buy have varied considerably. Currently, the NRO is paying for launch services under the Buy 2 contract.[8]

The "Buy 3" strategy extends from FY 2006 to FY 2011 and will consist of 22 launches notionally split evenly between Lockheed Martin and Boeing. The contractors are not guaranteed a specific number of launches—the basis for the notional split was to maintain stability in the industrial base and business case of each company.[9] Government documents indicate that the "assured access funding" in Buy 3 is expected to decline each year.[10] In the Buy 3 contract, the Air Force and the NRO will share supporting infrastructure costs, with the Air Force paying approximately 70 percent and the NRO paying approximately 30 percent of the costs. The exact dollar amounts are being negotiated, but the expectations of the Air Force and the NRO are that infrastructure costs will increase. Figure 4.2 identifies the NSS launches by executing agent and contract for 2005 to 2020. As reflected the figure, the last "Buy 1" vehicle is not scheduled to be launched until 2013.

The Buy 3 acquisition strategy is designed to better predict and manage costs by breaking the effort into two contracts—a fixed-price contract for an annual order of launch vehicles and a biannual, cost-plus contract for infrastructure support. Each year, the Air Force will review the manifest to identify changes and to place an adjusted order for launch services. This fixed-price launch services contract acquires cores and upper stages, payload fairings and adapters, mission-unique hardware, mission assurance instrumentation, booster storage costs, and mission success incentives. The cost-plus-infrastructure contract includes launch site and factory facility depreciation and amortization (including production tooling), lease costs, launch and range operations, mission integration and assurance, special studies, program management and systems engineering, training, supplier readiness, and transportation. Infrastructure costs are major factors in the total cost of ownership.[11] Currently, each contractor's infrastruc-

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[6] Interviews, senior Air Force officials, March 15, 2006.

[7] Initial Buy 2 contracts split the six launches evenly between Lockheed Martin and Boeing. Subsequent PIA actions caused Boeing to lose its three missions, although one mission was later reallocated to Boeing, resulting in the 5-1 split.

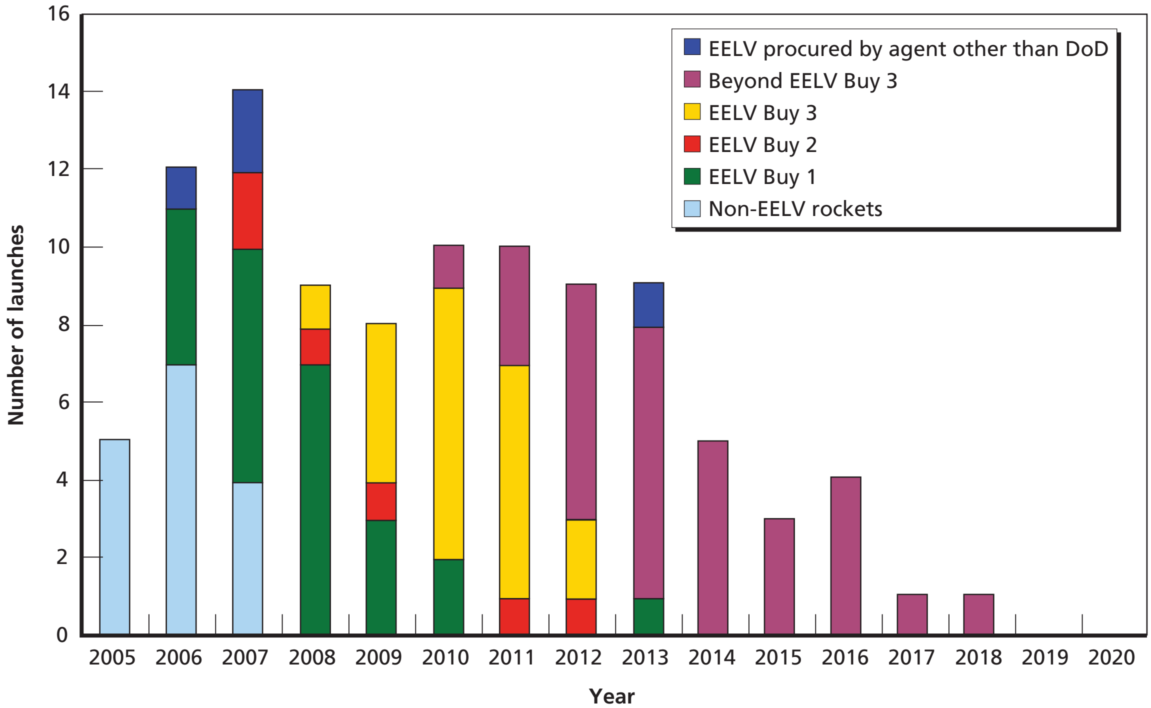
[8] Interviews, senior Air Force officials, December 16, 2005.

[9] Interviews, senior Air Force officials, December 5, 2005.

[10] This funding will decrease each year after FY 2005 ($54 million, $50 million, $40 million in 2006 to 2008, respectively) until it is concluded in FY 2009 (interviews, senior Air Force officials, December 5, 2005).

[11] Monitor Company Group, *Project Aurora: Final Report*, Washington, D.C., February 28, 2005, p. 29.

Figure 4.2
The Current NSS Manifest of Launches from 2005 to 2020, by Executing Agent and Contract



SOURCES: See the multiple sources listed in Figure 1.1.
NOTES: This chart reflects the March 2006 Air Force mission manifest, not the schedule or annual launch rates discussed in Chapter One. Two Buy 1 launches took place in 2003. One Buy 1 launch and Two Buy 3 launches have been omitted because they were R&D payloads. Data current as of March 15, 2006.
RAND *MG503-4.2*

ture costs are estimated to be $300 million to $360 million each year. The Buy 3 strategy also creates contractual opportunities for new contractors who might be competitive with the EELV in terms of performance, reliability, and costs, although precisely how this will occur is not clear as of this writing. The infrastructure contracts will be implemented within the next few months, while the launch services contracts are planned to begin between April and June 2006.[12]

The Buy 3 contracts will use provisions of the Federal Acquisition Regulation (FAR) Part 15 that specify requirements for costing and pricing data. This should provide the government with a good database for future management decisions. The government funding for Buy 3 will facilitate the continuation of two launch providers until roughly 2010, when the buy orders are completed. The terms and requirements for "Buy 4" have not yet been defined.

A key goal of the Buy 3 strategy is to attain system reliability by stabilizing the program. The government believes that the EELV is a developing system and lacks maturity at this time. Therefore, the system must be evaluated over the next several years for its reliability and perfor-

[12] Interviews, senior Air Force officials, March 14, 2006

mance. Flight and ground systems are too immature to identify meaningful ownership costs. Until these data are gathered and evaluated, it is unwise for the government to make any decision about retaining two vehicle families or down-selecting to a single vehicle family.

Launch Costs

Launch costs constitute various percentages of the total life-cycle costs for a space-based capability. The costs depend on the type and complexity of the payload being launched. Precise cost data are difficult to obtain and therefore must be assessed in terms of constant or actual dollars and what are included in the cost data. However, it is reasonable to estimate that for payloads costing around $1 billion, launch costs will range between 10 and 20 percent of the total launch vehicle and payload total cost. For typical commercial payloads, launch constitutes approximately 35 to 40 percent of the total costs, while for smaller payloads, such as GPS, launch costs are about 50 percent of the total cost. With few exceptions, payload costs are almost always equal to or greater than launch costs. Reliability is therefore a major factor in considering any program changes. Space services ownership cost is tied directly to launch system reliability. Hence, the cost of a failed launch is very significant—not only from the loss of the capability of the mission but also from the cost to the customer.

To a significant degree, reliability depends on maintaining a minimum number of launches necessary to ensure workforce proficiency in factory and launch operations. Proven reliability can be demonstrated only through repeated launches that validate design and process proficiency. The number of launches needed to establish reliability is subjective, and different government studies have yielded different numbers.[13] However, assessments are reasonably consistent and range between two to four launches per year to sustain confidence in reliability and resiliency while providing some program stability. An examination of the manifest in Appendix A indicates that in some years the launch rate for each EELV family is very close to these minimum numbers of launches. The EELV program would benefit from an increase in launches. The most likely source of these potential additional launches is NASA's science and International Space Station (ISS) resupply missions. At this time, the launch vehicle for many of these missions has not been selected. The government also believes that over the course of Buy 3, the numbers of launches will provide sufficient performance data on the two families of vehicles to allow development of an informed "Buy 4" strategy.

Cost-Related Issues

The Panel identified two major Atlas V issues that shape the EELV program and could well define future government courses of action. These issues are (1) the need to develop an Atlas V heavy-lift capability and (2) the production of the Russian RD-180 engine. These issues, discussed below, should be addressed rigorously early on.

The Atlas V was initially designed to include a three-CCB heavy-lift variant, but the variant has not yet been developed. The launchpad at the Eastern Range was designed to permit modification to accommodate a heavy-lift variant; however, this modification is a significant

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[13] Studies include the 1994 Moorman Study, the 2005 Monitor Corporation Study, and the 2002 Aerospace Commission Study.

task. The launchpad at the Western Range cannot be modified to accept a heavy-lift variant, and a new pad must be designed and constructed. These efforts to acquire an Atlas V heavy-lift capability will require a major investment. The Delta IV, however, has developed and demonstrated a heavy-lift capability, and the launchpads on both ranges are capable of launching the heavy-lift variant. In short, the Delta IV has a heavy-lift capability, but the Atlas V does not. If the U.S. government wishes to have an option in the post-2010 time period to identify and down-select to the superior vehicle, then it must address the heavy-lift issue in the near term. The manifest outlined in Appendix A reflects a modest requirement for six heavy-lift missions post-2010. One is an NRO mission now scheduled in 2015, and the other five are Transformational Communications Satellite (TSAT) missions scheduled to be launched between 2013 and 2018. The satellites for these missions are early in their design phase, and their masses are best estimates at this time. Therefore, given the state of design for the satellites and their associated launch schedules, a basic question to be addressed is, "Will the Atlas V (55x) lift capability satisfy the post-2010 heavy-lift requirements, and if not, what is the proper course of action to be taken?" Currently, the U.S. Air Force indicates that the Boeing Delta IV Heavy falls slightly short of meeting the performance needed for an NRO mission scheduled to launch before 2010. The Air Force is confident that modifications to the Delta IV will provide sufficient lift. The cost of these modifications to attain the required performance improvement is estimated to be on the order of $200 million.[14]

The use of the Russian-manufactured RD-180 engine in the Atlas V common core is a major policy issue that must be addressed in the near term. Current and past space policies have prohibited dependence on a foreign-made major critical component. There is no "off-the-shelf" replacement for the RD-180—produced either on or off shore. Everyone we interviewed contends that the RD-180 is technically advanced and highly reliable. The engine has demonstrated outstanding performance during all the Atlas III and Atlas V flights conducted to date. Lockheed Martin has an agreement with the Russian manufacturer to permit coproduction of the engine in the United States by Pratt & Whitney Rocketdyne. The Air Force and Lockheed Martin indicate that the Russians have done a good job of sharing technology and production information to permit coproduction of a reliable RD-180 engine in the United States. The Air Force's contract with Lockheed Martin calls for production capabilities in the United States by 2010 to comply with the NSTP requirement for a domestically produced launch capability. Currently, Lockheed Martin has a sizable stockpile of RD-180 engines, and Pratt & Whitney Rocketdyne is providing good technical support for the engine to the Atlas V program. Although the Air Force contract calls for Lockheed Martin to pay for the development of all onshore production capabilities, the Air Force acknowledges that ultimately it will have to absorb these costs given that it is the primary consumer of the capability. The cost to acquire a U.S. RD-180 production capability is estimated to be $500 million to $800 million.[15] However, it is acknowledged that the Russians might not have fully disclosed all the aspects of building the RD-180 in the United States and that in the end it might be difficult to

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[14] National Reconnaissance Office, Office of Space Launch, "NRO Launches (9/2005 thru 12/2015)," briefing to Panel, September 14, 2005.

[15] Discussions with Lockheed Martin officials, December 2005.

replicate the engine in U.S. production facilities. Alternatives to coproduction of the RD-180 include (1) stockpiling a supply of engines for future use to mitigate any interruption in the supply of engines, (2) coproduction of the most critical components (but stopping short of full coproduction) to demonstrate full understanding of the engine and to ensure a U.S. capability to solve technical problems independently, and (3) developing a domestic replacement for the RD-180. The U.S. government needs to address whether (1) Lockheed Martin must adhere to the contractual agreements given the potential technical and cost implications, or (2) whether the Air Force should seek relief for the contractor and continue with the current arrangement in which the contractor has significant technical knowledge and works with the Russians but does not build a U.S. production capability, or (3) whether to initiate a U.S. program to replace the RD-180.

The EELV program's objectives have been achieved as called for by the NSTP in terms of providing the nation an expendable launch capability for assured access to space that reduces the overall recurring costs of launch by at least 25 to 50 percent. The government has improved reliability and capability levels over the previous launch systems through better production and design engineering. In a 2004 report, the Government Accountability Office (GAO) indicated that the program met all the intent of assured access to space and has reduced government launch costs by approximately 51 percent over previous systems.[16]

In May 2005, Lockheed Martin and Boeing proposed a joint venture in which the two separate EELV families of vehicles would be maintained while key infrastructure would be consolidated. ULA would be a 50-50 joint venture (with no end date to the partnership) and would provide launch services to the U.S. government. ULA's goal is to reduce costs further, maintain workforce proficiency, sustain the modernized infrastructure thereby reducing overlapping functions, and improve utilization of resources. ULA advocates argue that reduced launch costs accrue over time as consolidation costs are amortized.[17] The venture will be managed by modifying the Buy 3 contracts. For the first three years, the government will pay the transition costs. After three years, according to the contractors, the government will save approximately $100 million to $150 million per year, or approximately 10 to 20 percent. The Office of the Secretary of Defense estimates that the cost savings will be $145 million per year and that the joint venture has the potential to prevent the divestiture of the launch business by one of the contractors (a major government concern) as well as the potential for significant cost savings. ULA provides the U.S. government another way to maintain two families of vehicles until a decision can be made regarding the proper course of action.[18] The ULA proposal is awaiting U.S. government approval at this time.

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[16] In May 2004, the EELV System Program Office estimated "launch cost savings of 51.4 percent over heritage systems." GAO (2004), p. 3.

[17] Michael Gass, Lockheed Martin response, June 7, 2005, p. 51.

[18] Interviews, senior government officials, December 16, 2005; interviews, senior government official, December 22, 2005.

Commercial and Foreign Launch Capabilities

The Panel also examined commercial and foreign capabilities in terms of costs. The keys to commercial launch capabilities are proven reliability and a low cost base. The Air Force states that if a commercial launch capability can meet the service's Key Performance Parameters (KPPs), then it can be considered as an alternative to EELV (through the contractual opportunities provided for in Buy 3). Therefore, any potential replacement of the EELV must meet the same criteria as the EELV.

The EELV KPPs and goals identified in the 1998 U.S. Air Force Space Command's Operational Requirements Document (ORD) were helpful to the Panel as an analytic tableau for the assessment of existing and proposed launch capabilities. They represent the U.S. government's goals for providing a launch capability consistent with the goals of the NSTP.[19] They provide the measures by which new launch capabilities are assessed for use by U.S. government payloads. The EELV ORD specified several requirements that later were translated into the KPPs in the EELV acquisition strategy. Four KPPs were identified to ensure the United States' ability to launch all payloads manifested in the National Launch Forecast safely and effectively: (1) the ability to launch the mass-to-orbit of the missions listed in the government portion of the National Mission Model,[20] (2) vehicle design reliability (with a threshold of 98 percent), (3) standard launchpads that must be able to process and launch all configurations of EELV from that site, and (4) standard payload interfaces for each vehicle class. The ORD also includes availability (call-up and launch within 45 days) and cost (a 25-percent cost reduction over current systems) as major system goals.[21]

Most commercial launch services contend that they have a substantially lower cost base. To compete, commercial launch services must also prove that they have flexibility in terms of backup capabilities, surge capability, and the ability to launch quickly after contract award. One of these commercial launch services, the Space Exploration Technologies Corporation (SpaceX) Falcon 9 rocket, was conceived in early 2005 (reportedly in response to a request by a "U.S. government customer"). SpaceX states that the objective of its business model is high design reliability and efficiency coupled with very low overhead and cost, thereby facilitating its ability to compete in the medium- and heavy-lift launch market. Initially, SpaceX had stated its intent to service the small vehicle and satellite launch market with its Falcon 1 vehicle.[22] The company said that it believed the small vehicle market to be very elastic and one that would grow rapidly if the low-cost vehicle were available. Later, SpaceX revised its plans to include the Falcon 9 and compete against the EELV program for U.S. government launch services.

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[19] GAO (2004).

[20] The seven DoD reference orbits (LEO, POLAR 1 & 2, SEMI-SYNC, GTO, MOLINIYA, and GEO) comprise the parameters for this particular KPP. As an objective, the medium and heavy vehicles should be able to support a growth of 5 percent and 15 percent, respectively (1998 AFSPC EELV ORD).

[21] The EELV meets most of the KPPs outlined in the AFSPC ORD. System immaturity has prevented full compliance at this point in time, but full compliance is expected to be achieved as the program evolves.

[22] In its first Falcon 1 launch, a fuel leak and fire around the main engine destroyed the rocket and scientific payload shortly after launch on March 24, 2006. The rocket was being launched from the Kwajalein Atoll. Tariq Malik, "Fuel Leak and Fire Led to Falcon 1 Rocket Failure, SpaceX Says," SPACE.com, March 26, 2006.

The evaluation of Falcon 9 at this time presents an unclear picture. The overriding concerns are its reliability and availability. The first Falcon 9 launch is scheduled for the second quarter of 2007. The lack of launch experience raises questions about the validity of the available launch prices—estimated by SpaceX to be $27 million to $35 million per launch, depending on the size of the payload fairing. The lack of common on-ramp criteria for "Buy 3" makes an objective evaluation of the actual costs of this new vehicle extremely difficult. The remaining KPPs (mass-to-orbit, launch cycle times and sites, and standardization) cannot be appropriately measured in this case because of the lack of launch and performance data.

The Panel also evaluated foreign-developed launch capabilities. Although the NSTP prohibits the use of foreign launch services, the Panel wanted to determine how foreign launch capabilities and costs compared with those of the EELV. A launch capability is, in many instances, a national objective. Recently, there has been a significant increase in foreign-government-subsidized and foreign-government-developed launch capabilities. Europe, China, Russia, and India have all entered or are entering the marketplace with subsidized programs to maintain a national capability. In addition, Japan, Brazil, and South Korea are working on national launch capabilities. These nations are offering low launch costs through government subsidies in hopes of sustaining a low cost base, increasing their launch rates, and, ultimately, improving the system's reliability. These initiatives result in growing pressures to drive launch costs down to about $10,000 to $12,000 per pound of payload. Most of these launch capabilities are priced well below average recurring cost based on the same analysis used in the Falcon 9 case. It is impossible to find the true development costs of these systems, but in all these cases the governments' desire to have a national launch capability outweighs the actual costs.

Arianespace is representative of a foreign launch company launching below cost. As Europe's entry into the heavy-lift commercial launch arena, the company's Ariane 5 has met with mixed results since development was started in 1987. An initial up-front investment of $9 billion for development was followed by an additional $3 billion to fix technical problems identified in the official accident reviews following two launch failures for the first ten vehicles. In addition to technical problems (four partial or total launch failures, including the maiden flight of the Ariane 5G in 1996),[23] cost is a major factor in the program's success. The launch costs for an Ariane 5 are in the $130 million to $150 million range, and this is after the "recapitalization" of $1.5 billion from European investors in 2004. High infrastructure costs, lower-than-expected global demand, the presence of only one launch site (in French Guiana), limited mass-to-orbit capacity, and, more importantly, increased saturation of the market with commercial and government competitors have decreased the Ariane 5's ability to compete globally. Nonetheless, Arianespace views Ariane 5 as a viable alternative to the U.S. space community's systems in the event that domestically manufactured systems cannot provide assured access.[24]

In the foreseeable future, the pressure on Ariane 5 is likely to build to the point that, without subsidies, it cannot survive. Its launch schedule assurance contributes to high insurance rates and capacity problems for too much value on a single payload. To solve this problem, Arianespace has an agreement with Boeing Launch Services, which operates the Sea Launch

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[23] Out of 23 total launches to date—equating to an approximate 83-percent launch success rate.

[24] Meeting notes, Space Launch Study Panel, June 6, 2005.

Zenit vehicle system, to offload payloads where it makes sense, in essence providing better launch schedule assurance. Other foreign government subsidized competitors will further pressure the launch provider. Land Launch, which uses the same Zenit as the Sea Launch, and Soyuz will challenge the small and medium market in which Ariane 5 needs a small satellite to fly with a big satellite on a dual launch. The problems of cost, dual-launch strategy, and declining market demand further exacerbate the increased foreign competition that severely challenges Arianespace's business case and ultimately its survival.

Based on the analysis above, the Panel concluded that without U.S. government intervention, the EELV family will capture only a small share of the commercial market.

Findings

1. The EELV program provides two families of vehicles—the Atlas V and the Delta IV—that meet the objectives of "assured access" to space, and the U.S. government is committed to using both vehicles through at least the 2010 time period.
2. These vehicles will most likely not be competitive on the highly subsidized world commercial market. The U.S. government must accept that it will be the dominant user of the EELV and is therefore responsible for bearing the costs of maintaining the systems for the foreseeable future.
3. Because of the immaturity of the Atlas V and Delta IV vehicles, reliable performance and cost of ownership data are currently unavailable to permit an objective determination of the superior vehicle.
4. The U.S. government should focus on cost-effective means to manage the current EELV program costs and to identify and collect the performance and cost of ownership data needed to make an objective decision regarding the course to pursue in the post-2010 time period.
5. The Buy 3 strategy appears reasonably sound and offers one way that near- and midterm costs can be managed, particularly in a period when few changes are expected in the launch market in terms of a rising demand. However, if the U.S. government does not make key decisions concerning the heavy-lift requirements and RD-180 engine before the initiation of the Buy 3 contract, then it must make these decisions early in the 2006–2009 time frame. The Panel strongly urges the U.S. Air Force to lay out a plan that identifies the data—total ownership costs, reliability, performance of each family of vehicles—to be gathered during Buy 3. The information is essential to defining the way ahead and the potential structure of Buy 4.
6. While there is concern that ULA could create a monopoly or monopsony condition, the Panel cannot find anywhere in the U.S. government that this deviates from established large-scale weapon system acquisitions. The Panel was unable to validate the cost savings promised by ULA; however, ULA will provide management advantages to the EELV program. If the program is managed properly, then the U.S. government will have reliable data to define future courses of action that are best for the nation.

7. The Buy 3 plan provides natural strategic time periods for the introduction of a commercial launch vehicle, if such a suitable alternative exists. The U.S. government should identify the criteria by which to judge the suitability of a commercial alternative launch vehicle to the Atlas V and Delta IV. These criteria should be made available to potential offerers so that they can evaluate the business case accordingly.
8. The Buy 4 strategy that further refines the contracting vehicles and clarifies cost profiles should be developed at an early date. Although the government argues that it is only now initiating the Buy 3 activities, the Panel finds that the buy strategy should be viewed as a series of interdependent decisions that are implementing an overall strategic plan of how to manage and afford U.S. launch capabilities.
9. NASA's use of the EELV for all appropriate unmanned missions should be carefully evaluated. If NASA chooses to deviate from the use of the EELV, then it must justify the decision from a technical or economic perspective in accordance with the organizational and functional review mechanisms defined in the NSTP.
10. The U.S. government's decisionmaking on launch capabilities will occur in an environment of global oversupply and relatively flat demand for launch services. The U.S. government decisionmakers must not be so focused on EELV cost savings and affordability that the most important KPP—reliability—is compromised, particularly in NSS payloads, which are usually mission essential, mission unique, and mission expensive.

CHAPTER FIVE
Architectures and Operational Concepts

Tasking

This chapter responds to specific tasking from House Resolution 4200: "The report shall include … the assessment and any recommendations of the Panel, on (A) launch operational concepts and architectures."

Discussion

NSS Launch Architecture

The NSTP, dated December 2004, provides the overarching architecture for the NSS programs. In part, the policy establishes a requirement for "assured access to space" for NSS programs, appoints DoD as the launch agent for NSS programs, and designates the EELV as the foundation for access to space for intermediate and larger payloads for NSS programs. Additionally, the policy directs the Secretary of Defense to continue the services of both EELV launch families until such time that a single vehicle family can provide the required assured access to space. The Panel believes this architecture to be fundamentally sound and does not recommend any changes to it at this time.

The Panel views the DoD EELV efforts to be compliant with the architecture outlined in the NSTP. While the Atlas V and Delta IV launchers are immature systems at this time, both have demonstrated the capability to meet the fundamental policy goal to ensure the capability to access space in support of national interests. The Air Force has developed a strategy and has planned or programmed the resources to support both launch families until such time that sufficient data are available to permit an objective selection of the proper course of action to follow with respect to keeping two EELV families or down-selecting to a single family.

Emerging Operationally Responsive Space Concepts

Significant interest has arisen in developing a new and "more responsive" military launch capability. Several studies and demonstrations are in progress to identify specific Operationally Responsive Space (ORS) concepts. ORS relies on smaller payloads (some as small as 1,000 pounds), quicker call-ups, shorter processing, and quicker turnaround and possibly all-azimuth (independent of the geographic constraints of current launch ranges) launch capability to provide combat commanders with additional space capabilities for warfighting. Proponents say that, in addition to providing new capabilities, the ability to launch smaller rockets more frequently would have the side benefits of improving system reliability as well as crew training, currency, and performance.

ORS Mission. Several missions are being studied that would exploit the utility of a more responsive launch capability.

> The intent of Operationally Responsive Space (ORS) is to create a more responsive, reliable, and affordable lift family capable of fulfilling both current and future launch requirements, and the corresponding responsive and affordable satellites. Near term, we plan to demonstrate a more responsive and less expensive launch system with capabilities of 1,000 pounds to low earth orbit. Concurrently, Air Force Space Command, AFRL [Air Force Research Laboratory], the NRO, DARPA, OSD's Office of Force Transformation, and our national and Service laboratories are sponsoring Tactical Satellite (TacSat) initiatives focused on responsive satellites, and decreasing the size, cost, and timelines of development. The combined efforts of these initiatives—operationally responsive launch and satellite development—will transform the delivery of space-based capabilities.
>
> —*Peter B. Teets, Under Secretary of the Air Force, 2004*[1]

The DoD Space Science and Technology Strategy calls for developing space technologies that will enable rapid deployment of launch systems.[2] Several demonstrations are under way for more responsive satellites and for a lower cost, more intercontinental ballistic missile–like responsiveness for achieving at least the ability to put a low-mass payload into LEO.

One ORS concept being discussed in the Air Force would seek to provide a launch capability as a weapon system dedicated to the combatant commander. This new concept is focused more on the military needs of the combatant commander than on the traditional NSS customers. Congress has shown interest in ORS concepts by passing a bill requiring that, before 2010, the United States shall demonstrate an initial capability for "operationally responsive" access to and use of space to support NSS requirements.[3] This system would be assigned to the

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[1] Statement by Under Secretary of the Air Force Peter B. Teets before the Committee on Armed Services, House of Representatives, Subcommittee on Strategic Forces, regarding the FY 2005 National Defense Authorization Budget Request, February 25, 2004.

[2] DoD Space Science and Technology Strategy 2004, signed by Peter B. Teets, DoD Executive Agent for Space, and Ronald M. Sega, Director Defense Research & Engineering, January 31, 2004, p. 3.

[3] The congressional language is as follows (2273a): "a separate, dedicated program element for operationally responsive national security payloads and buses of the Department of Defense for space satellites and programs and activities for such payloads and buses are planned, programmed and budgeted for through that program element."

This also assigns "management authority for the program element required under subsection (a) to the Director of the Office of Force Transformation of the Department of Defense." The provision in 2273a also defines "the term 'operationally responsive,' with respect to a national security payload and bus for a space satellite, means an experiment of operational payload and bus with a weight not in excess of 5,000 pounds that can be developed and acquired within 18 months after authority to proceed with development is granted; and is responsive to requirements for capabilities at the operational and tactical levels of warfare."

appropriate combatant commander and would include a family of small, quick-response satellites to augment NSS services.

ORS Activities: The DARPA FALCON Program. In support of emerging ORS activities, DARPA has initiated the FALCON (Force Application and Launch from the Continental United States) program (separate from the SpaceX Falcon series of rockets) to address many of the uncertainties. Under FALCON, DARPA and the Air Force are developing a small launch vehicle for rapid global reach. The objective of the program is to develop a capability to place 1,000 pounds into a 100-nautical-mile circular orbit. Of the nine contractors' concepts that were submitted to DARPA during Phase I of the project, four were funded in September 2004 for preliminary design and development work (see Figure 5.1). Although only two of those contractors still remain in competition, an overview of the basic technology of the Phase II designs follows.[4]

AirLaunch LLC, of Reno, Nevada, is designing the QuickReach space launch vehicle. Intended to be air-dropped from a C-17 aircraft, the propane propellant used in the rocket is entirely pressure fed. A successful drop test from an airborne Air Force C-17 was demonstrated on September 29, 2005.[5]

SpaceX, of El Segundo, California, is on a slightly different path from its competitors because its Falcon 1 rocket has received launch orders and support from sources outside of DARPA. Extensive testing of the space launch vehicle components led DARPA to award money to SpaceX for a trial launch of the vehicle (and a FalconSat payload). The test flight was unsuccessful in March 2006.

A third competitor, Microcosm Inc., also in El Segundo, was originally being considered for its Eagle space launch vehicle. Despite a successful engine test in May 2005, the company broke up its subcontract agreements in August 2005, eliminating itself from competition.[6]

Lockheed Martin Michoud Space System's design concept for its Hybrid Mobile Launch System was the fourth of the Phase II FALCON competitors. Although its RR101 hybrid liquid- and solid-propellant motor was successfully tested in January 2005, the design was withdrawn from FALCON competition in September 2005.[7]

Payloads. On the satellite side, responsive payload concepts today are ill defined and need validated requirements. No DoD Integrated Capabilities Document has been formulated for these systems; the systems are not slated to become operational before 2018, at the earliest; and even that would depend on a clearer definition of the mission, sufficient funding, and "normal"

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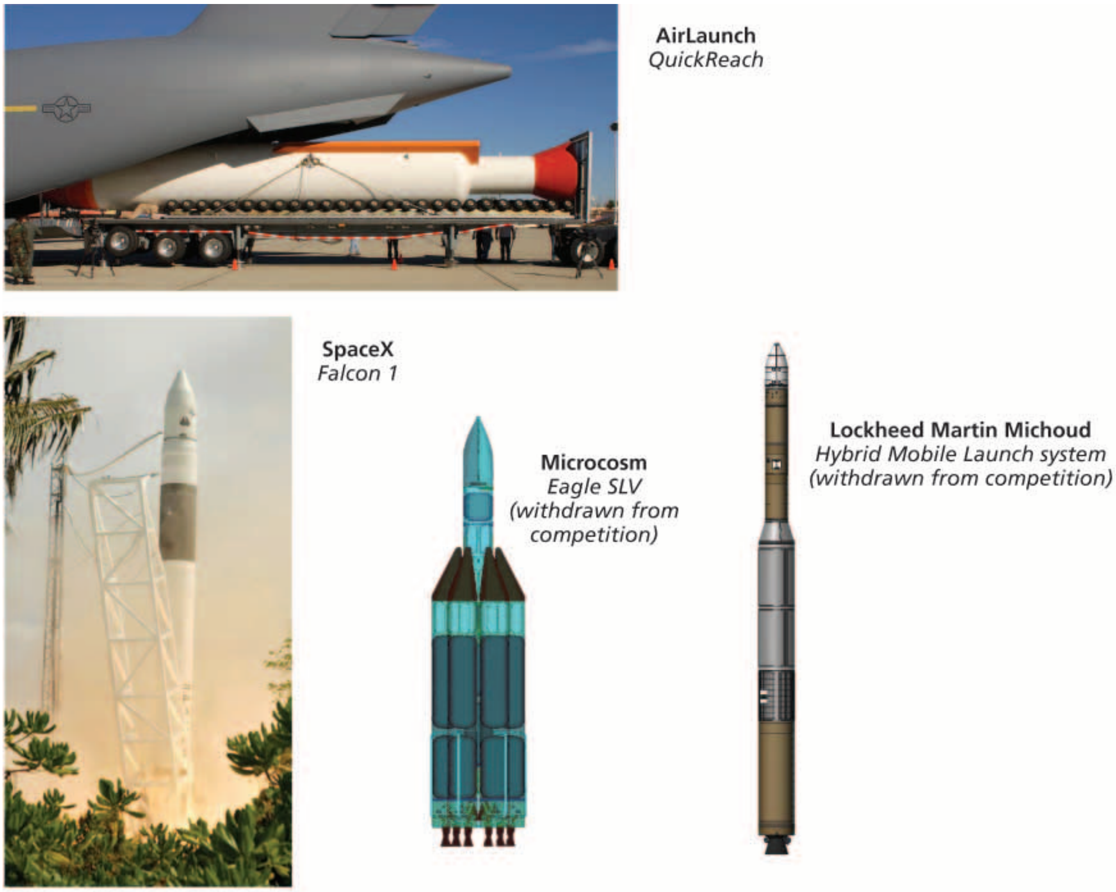
[4] All DARPA FALCON reference material and photos were taken from Steven H. Walker, DARPA, "FALCON Program Overview," briefing to the Panel June 6, 2005.

[5] This test dropped a mock-up version of the AirLaunch rocket from 6,000 feet. It was designed to test the safety of the release system. Future drops will be at increasingly higher altitudes, ultimately testing the drop of a live rocket, which will ignite after leaving the aircraft. Christopher Ball, "Edwards and DARPA Explore New C-17 Capability," Air Force Print News, October 7, 2005.

[6] Brian Berger and Jeremy Singer, "Field Narrows for DARPA's Falcon Program," *C4ISR: The Journal of Net-Centric Warfare*, August 29, 2005.

[7] Interview, senior DARPA official, March 30, 2006.

Figure 5.1
Design Concepts for the Four Phase II Competitors in the DARPA FALCON Program



SOURCE: Images provided by DARPA-TTO.

development. Many of the personnel who addressed the Panel agreed that the payload challenge is much greater than the technological task of creating an ORS booster.[8]

Launch. ORS launch requirements are dependent on the operational concept. Because the ORS operational concepts are in the formative stages, it is premature to specify launcher requirements. Some of the ORS concepts presented to the Panel envisioned launch response times of about 30 days. The EELV families have the potential to satisfy this 30-day "requirement." Other concepts require the development of a new family of quick-response small launchers. In any event, it is the judgment of the Panel that development of an ORS launch capability is not on the critical path to fielding an operational system.

Cost. The Panel has the following budget concerns regarding the ORS approach:

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[8] The Air Force Scientific Advisory Board study found that producing the desired fidelity for optical systems would drive the mass of the satellite beyond the demonstration weight payloads without using advanced optical technology that does not yet exist (Scientific Advisory Board briefing to CSAF, August 2004, presented to the Panel on November 14, 2005). Other payloads offer similar hurdles.

- *Opportunity cost.* As described earlier in this report, ORS should not be funded at the expense of the EELV program.
- *Booster cost.* While the booster cost of NSS systems is relatively small compared with the cost of the payload, this may not be the case for ORS concepts that employ a large number of small satellites. It is quite possible that launcher costs could be a sizable portion of the overall capability cost.[9] The ORS boosters being demonstrated under the DARPA project are attempting to lower launcher cost significantly.
- *Infrastructure cost.* An ORS system may require significant new infrastructure or major changes to launch facilities and ranges. The resources needed to fund these facilities should be considered in the overall ORS concept of operation and cost analysis.

Conclusions. Experiments and studies are in progress by the Air Force and DARPA to identify ORS concepts and requirements in accordance with the NSTP. The pace at which these activities proceed should be in consonance with the development of concepts of operations and operationally useful payloads. The IOC for any such systems will most likely occur after 2015.

Findings

1. The NSTP defines a sound space launch architecture, and DoD is implementing the NSS launch provisions.
2. The U.S. government should continue the ORS experiments and demonstrations. However, ORS full-scale development should not be undertaken until an operational concept, a family of candidate payloads, and launch vehicles and infrastructure are aligned.

[9] The Panel discussed this issue with personnel from AFRL and AFSPC.

CHAPTER SIX

Launch Technologies

Tasking

This chapter responds to specific tasking from House Resolution 4200: "The review and assessment shall take into account … launch technologies, including (i) reusable launch vehicles, (ii) expendable launch vehicles, (iii) low cost options, and (iv) revolutionary approaches."

Discussion

The Panel's efforts have focused on identifying the compelling mission requirements that define the future launch demands, allow the development of launch architectures, and identify the technology shortfalls to meet these demands.

National Science and Technology Council–4 assigned NASA the responsibility for developing reusable launch vehicle technologies. DoD was responsible for expendable launch vehicle technologies and has participated in NASA's technology programs as a partner in select technologies deemed to be relevant to NSS launch needs. With the NSTP, NASA has changed its focus and investment away from advancing reusable technologies to the NASA Exploration Initiative ("…Moon, Mars and Beyond.").[1]

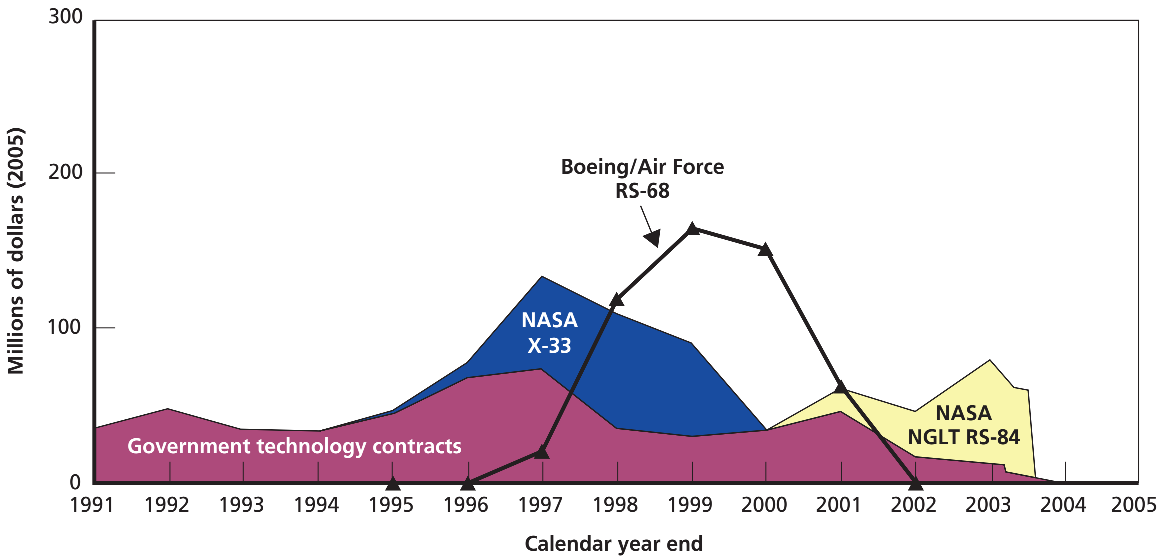
EELV Technology Needs

The Atlas V and Delta IV vehicles incorporate current state-of-the-art technology. No additional advanced technology needs were identified by the Panel to support these vehicles for the foreseeable future. Normal "product improvement" efforts to marginally improve performance, manufacturing, and launch processing efficiencies are to be expected.

As previously noted in this report, the Delta IV CBC uses a recently developed liquid oxygen and hydrogen engine (RS-68). Figure 6.1, provided to the Panel by Pratt & Whitney Rocketdyne, the largest domestic liquid propulsion manufacturer, depicts the major invest-

[1] A central component of which is "embarking on a robust space exploration program to advance U.S. scientific, security, and economic interests. A central component of this system is to extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations."

Figure 6.1
U.S. Government Liquid Propulsion Rocket Investment, 1991–2005



SOURCE: Byron Wood, Pratt & Whitney Rocketdyne, "Future Launch Vehicle Requirements," briefing to the Panel, September 14, 2005.
RAND *MG503-6.1*

ments in rocket propulsion over the past 15 years. The only large investment at Pratt & Whitney Rocketdyne has been in the liquid oxygen and hydrogen engine for the Delta IV. There have been no major investments in liquid oxygen and kerosene pump-fed engines since the development of the Atlas and Thor ballistic missiles more than 30 years ago. In contrast, the Russians have continued to advance this technology. One of the desirable traits of a liquid oxygen and kerosene rocket engine is the ease of storing and handling the fuel (kerosene). The Atlas V (and previously Atlas III) designers desired to continue the use of a liquid oxygen and kerosene pump-fed engine. There were two Russian candidate engines: the RD-180 and NK-33. No engines of this type were available from U.S. sources. Accordingly, the Russian RD-180 was chosen. It has proven to be a reliable, state-of-the-art, high-performance engine using modern designs, materials, and processes.

When the RD-180 was tested at the NASA Marshall Space Flight Center in Huntsville, Alabama, engineers recognized the level of technology used in the RD-180 and initiated a program to advance the U.S. liquid oxygen and kerosene rocket engine technology. This effort was part of the NASA Next Generation Launch Technology (NGLT) program. These programs were terminated in 2005, and the resources were redirected to the Exploration Initiative. As previously discussed in this report, U.S. policy required all major components of the EELV family to be produced in the United States, which led to the initiation of coproduction of the RD-180. An alternative to coproduction of the RD-180 is the development of a replacement U.S. engine, possibly reviving the canceled RS-84 program, which was a part of the NGLT. Such a program would revitalize the U.S. liquid oxygen and kerosene technology and industrial base.

Current Technology Investment

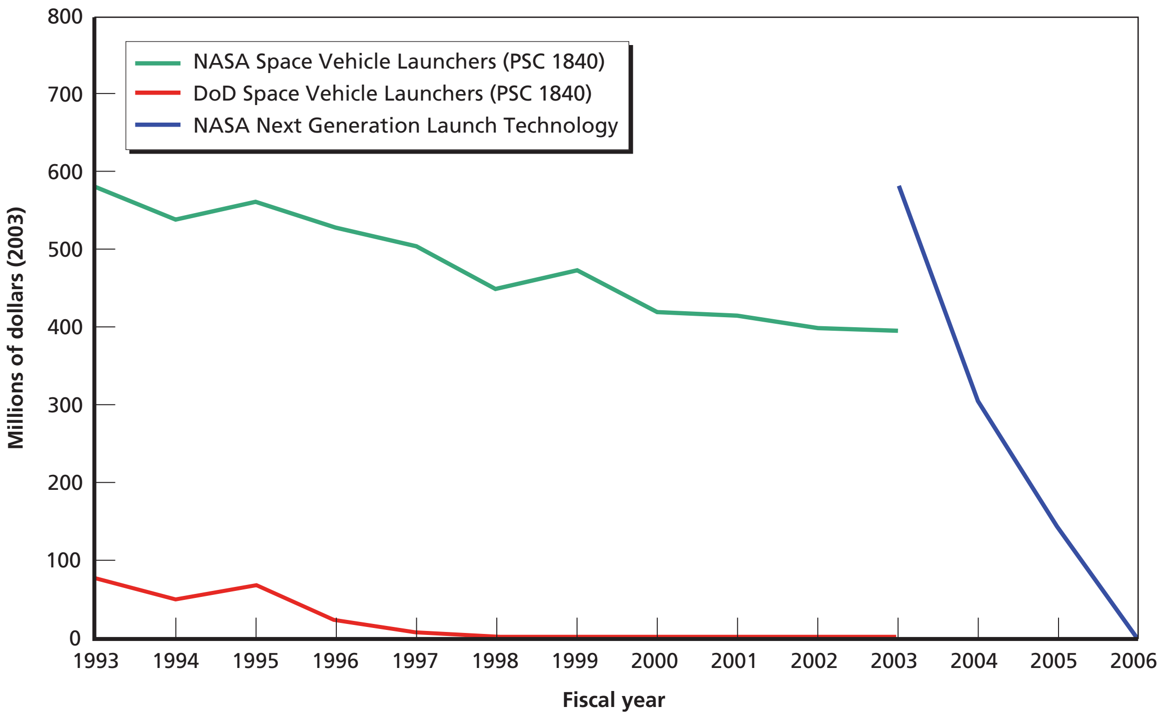
The termination of the NASA-managed National Launch Initiative, which includes the NGLT program, decreased the investment in earth-to-orbit technologies to the point where the remaining effort is irrelevant. The lack of a corresponding technology program within DoD has created a technology funding gap. The lack of defined requirements to support the justification for a launch technology investment by DoD will hamper any future systems development. The downward trend of national investment in launch technology was recognized as early 1994 in the DoD Space Launch Modernization Plan (known as the "Moorman Study"), which stated, "A significant finding is that core space launch technologies, such as propulsion and new materials are significantly under funded." In 2002, the Final Report of the Commission on the Future of the U.S. Aerospace Industry noted in its recommendations: "The Department of Defense, NASA and industry must partner in innovative aerospace technologies in propulsion and power. These innovations will enhance our national security, provide major spin-offs to our economy, and accelerate the exploration of the near and distant universe with human and robotic missions."

The erosion in U.S. investment to enable future systems development was presented to the Panel during discussions with several industry representatives. The information in Figure 6.1 shows that the government investment in liquid rocket propulsion has decreased significantly and is projected to end in 2006. This lack of an investment in technology has had significant effects on the nation's space launch capability: significant reductions in the available workforce with critical technical skills, the loss of the space launch research infrastructure within the government and university community, the decline of the industrial base (especially the R&D workforce), reliance on foreign technology by industry for components and systems developed overseas (e.g., RD-180, high-temperature materials, selected electronic components), and the lack of technology to support the development of future launch systems.

A 2005 RAND report by noted that federal expenditures in aerospace R&D at both DoD and NASA are declining. DoD expenditures in aerospace R&D dropped 50 percent between 1991 and 2005, excluding a single-year spike in expenditures in 2003. NASA's external expenditures in aerospace R&D declined 35 percent from 1993 to 2003. NASA offset relatively small cuts in space systems with large cuts in infrastructure maintenance and basic R&D. Figure 6.2 illustrates the decline in launch vehicle R&D from 1993 to 2003 in constant 2003 dollars. DoD investment in launch vehicle R&D declined from $77 million in FY 1993 to zero in FY 1998. NASA investment in launch vehicle R&D declined in FY 2003 from $580 million to $395 million. The figure presents the NASA and DoD funding for space vehicle launchers.

NASA did perform additional research in launch-relevant technologies, some of which are also included in Figure 6.2. In the early 1990s, NASA invested more than a half-billion dollars annually into the Space Launch Initiative (SLI), a program with the goal of developing a new reusable launch capability. Beginning in FY 2003, the SLI budget was shifted into the development of the Orbital Space Plane and NGLT programs. In FY 2005, NASA shifted funding of the Orbital Space Plane program to the development of the Crew Exploration Vehicle, which received $428 million in budget authority. The NGLT program was terminated in FY 2005 and did not appear in the FY 2006 budget.

Figure 6.2
Federal R&D in "Space Vehicle Launchers (1840)" and the NASA NGLT Program, 1993–2003



SOURCES: RaDiUS, available at http://radius.rand.org/; GlobalSecurity.org, "Transportation Systems," 2004.
RAND *MG503-6.2*

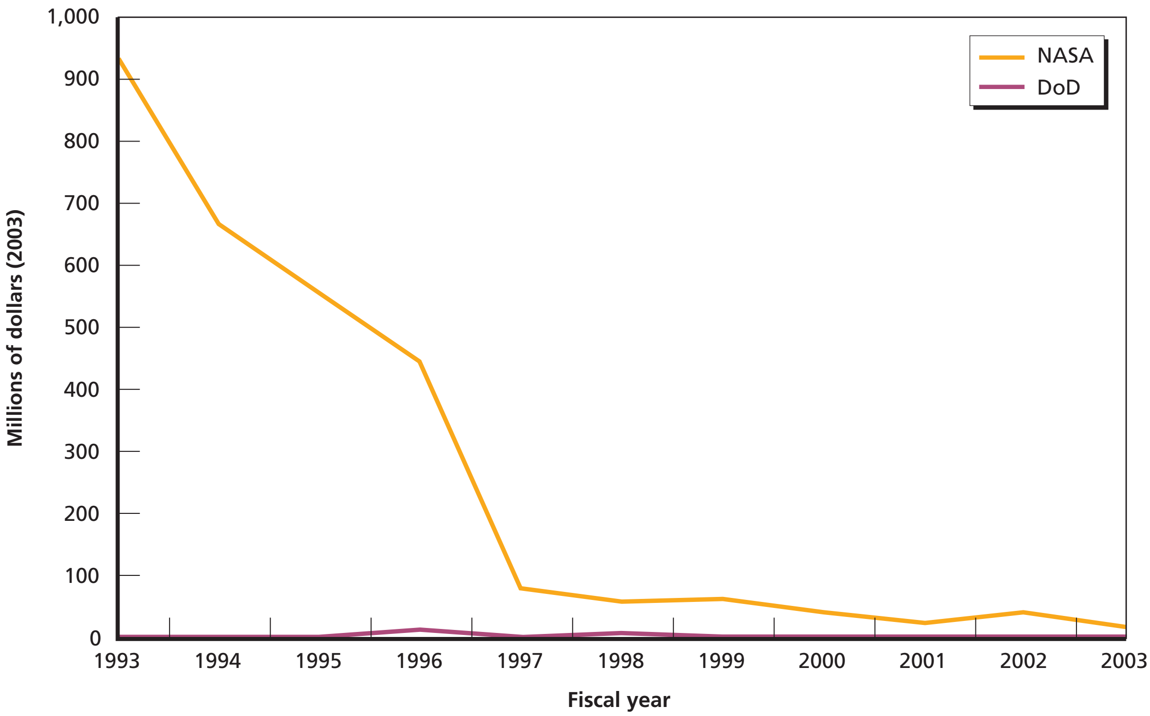
A critical component of a launch vehicle is the rocket engine and its related technology. Figure 6.3 depicts federal R&D in rocket engines and components funded by NASA and DoD from 1993 through 2003.[2] While DoD invested little in this area—its expenditures never exceeded $16 million in 2003 dollars—NASA's investments declined precipitously. In 1993, funding for rocket engines and components was $929 million. By 2003, the funding in this area was $21 million. During this time, Boeing internally financed the RS-68 engine, and NASA completed major block upgrades of the Space Shuttle Main Engine.

Reusable Launch Vehicles

Because of the significant cost of launch vehicles, there has been a long-term desire on the part of policymakers to build a reusable launch vehicle that would spread launch vehicle costs over a number of missions. Reusable launch vehicles require unique technological performance (high vehicle mass-fraction and thrust-to-weight ratio) and operational systems (reusable thermal protection systems) not required for expendable vehicles. To offset the increased cost of these

[2] Product Service Code 2845.

Figure 6.3
Federal R&D in "Rocket Engines and Components (2845)," 1993–2003



SOURCE: RaDiUS, available at http://radius.rand.org/.
RAND *MG503-6.3*

technology and operational requirements for a reusable vehicle, a high flight rate needs to exist to justify the investment.

To date, the Panel has not been presented the requirements for high launch rates that justify the case for reusability. With the lack of definitive mission needs and the currently projected technology investment, the Panel finds that any operational reusable launch vehicle falls beyond the time frame of this study.

Revolutionary Space Launch Approaches

The Panel did not identify any emerging technology that will have a major influence on earth-to-orbit launch capability within the 2020 time frame of the study. As was previously stated, the national investment in the development of launch vehicle technology has been very low over the past decade. Several unique capabilities could be provided for future systems applications. The identification of requirements for very high launch rates could justify the investment in single, two-stage-to-orbit reusable systems enabled by the development of lightweight structures, lightweight tanks, and new high-performance propulsion systems. A requirement for an all-azimuth launch to insert payloads into any orbital plane would benefit greatly from the development of systems with hypersonic air-breathing propulsion. If a compelling strategic need for these and other new capabilities is articulated and a significant investment is made in this critical technology, then systems with the capabilities discussed above will emerge only after the 2020 time frame of this study.

Although the Panel could not find a validated concept of operations for ORS, fact-finding briefings from AFSPC, AFRL, DARPA, and several industry sources presented ORS technology plans and advanced development concepts. ORS technology efforts funded by DARPA and the Air Force research labs are forecast to increase. Although flight demonstrations are proposed for 2017, no promising technologies were identified that will enable an operational ORS until after 2020. ORS technology efforts are proceeding with little definition of mission-derived requirements for identifying enabling technologies for these systems.

Findings

1. No advances of launch technologies required to meet NSS needs were identified—that is, NSS launch needs are adequately satisfied by existing technologies. Product improvements can be expected as the EELV program matures to enhance performance, reliability, and manufacturability.
2. The NASA investment in earth-to-orbit launch technologies has decreased to the point of being irrelevant. The loss of this investment will exacerbate the need to rely on foreign components and further erode the launch technology and industrial base.
3. The erosion of the industrial base to produce major new NSS launch systems and the loss of an experienced R&D workforce to meet future technology needs will continue without an investment in future technology needs.
4. ORS technology efforts funded by DARPA and the Air Force research labs are forecast to increase. ORS technology efforts are proceeding with little definition of mission-derived requirements for identifying enabling technologies for these systems. Although flight demonstrations are proposed for 2017, no promising technologies were identified that will enable an operational revolutionary system before the 2020 time frame of the study. With the projected technology investment, ORS capabilities that address all-azimuth launch and reusability will not be available until well after 2020.

APPENDIX A

The Current NSS Launch Manifest, 2001–2020

Figure A.1
The Current NSS Launch Manifest, 2001 to 2020 (PLACEHOLDER)

APPENDIX B

Related Materials

Space Launch Panel Charter, from House Resolution 4200, Section 912

H. R. 4200

One Hundred Eighth Congress of the United States of America

AT THE SECOND SESSION

Begun and held at the City of Washington on Tuesday, the twentieth day of January, two thousand and four

An Act

To authorize appropriations for fiscal year 2005 for military activities of the Department of Defense, for military construction, and for defense activities of the Department of Energy, to prescribe personnel strengths for such fiscal year for the Armed Forces, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005".

SEC. 912. PANEL ON THE FUTURE OF NATIONAL SECURITY SPACE LAUNCH.

(a) IN GENERAL.—(1) The Secretary of Defense shall enter into a contract with a federally funded research and development center to establish a panel on the future national security space launch requirements of the United States, including means of meeting those requirements.

H. R. 4200—217

(2) The Secretary shall enter into the contract not later than 60 days after the date of the enactment of this Act.

(b) MEMBERSHIP AND ADMINISTRATION OF PANEL.—(1) The panel shall consist of individuals selected by the federally funded research and development center from among private citizens of the United States with knowledge and expertise in one or more of the following areas:

(A) Space launch operations.
(B) Space launch technologies.
(C) Satellite and satellite payloads.
(D) State and national launch complexes.
(E) Space launch economics.

(2) The federally funded research and development center shall establish appropriate procedures for the administration of the panel, including designation of the chairman of the panel from among its members.

(3) All panel members shall hold security clearances appropriate for the work of the panel.

(4) The panel shall convene its first meeting not later than 30 days after the date on which all members of the panel have been selected.

(c) DUTIES.—(1) The panel shall conduct a review and assessment of the future national security space launch requirements of the United States, including the means of meeting those requirements.

(2) The review and assessment shall take into account the following matters:

(A) Launch economics.
(B) Operational concepts and architectures.
(C) Launch technologies, including—
(i) reusable launch vehicles;
(ii) expendable launch vehicles;
(iii) low cost options; and
(iv) revolutionary approaches.
(D) Payloads, including the implications of payloads for launch requirements.
(E) Launch infrastructure.
(F) Launch industrial base.
(G) Relationships among military, civilian, and commercial launch requirements.

(3) The review and assessment shall address national security space launch requirements over each of the 5-year, 10-year, and 15-year periods beginning with 2005.

(d) INFORMATION FROM FEDERAL AND STATE AGENCIES.—(1) The panel may secure directly from the Department of Defense, from any other department or agency of the Federal Government, and any State government any information that the panel considers necessary to carry out its duties.

(2) The Secretary of Defense shall designate at least one senior civilian employee of the Department of Defense and at least one general or flag officer of an Armed Force to serve as liaison between the Department, the Armed Forces, and the panel.

(e) REPORT.—Not later than one year after the date of the first meeting of the panel under subsection (b)(4), the panel shall submit to the Secretary of Defense, the congressional defense committees, the Select Committee on Intelligence of the Senate, and the Permanent Select Committee on Intelligence of the House of Representatives a report on the results of the review and assessment under subsection (c). The report shall include—

(1) the findings and conclusions of the panel on the future national security space launch requirements of the United States, including means of meeting such requirements;

(2) the assessment of panel, and any recommendations of the panel, on—

(A) launch operational concepts and architectures;

(B) launch technologies;

(C) launch enabling technologies; and

(D) priorities for funding; and

(3) the assessment of the panel as to the best means of meeting the future national security space launch requirements of the United States.

(f) TERMINATION.—The panel shall terminate 16 months after the date of the first meeting of the panel under subsection (b)(4).

(g) FUNDING.—Amounts authorized to be appropriated to the Department of Defense shall be available to the Secretary of Defense for purposes of the contract required by subsection (a).

Letter to the Office of Science and Technology Policy's John H. Marburger from Under Secretary of the Air Force Ronald M. Sega and NASA Administrator Michael D. Griffin (August 5, 2005)

August 5, 2005

The Honorable John H. Marburger III
Director, Office of Science and Technology Policy
Executive Office of the President
Washington, DC 20502

Dear Dr. Marburger:

In accordance with National Security Policy Directive 40, the Department of Defense (DoD) has coordinated on the space transportation strategy presented by the National Aeronautics and Space Administration (NASA).

Recognizing the benefits of leveraging existing capability, as well as the cost and schedule burdens placed on unmanned payloads launched using human-rated systems, we understand that the DoD and NASA believe that separating human-rated space exploration from unmanned payload launch will best achieve reliable and affordable assured access to space while maintaining our industrial base in both liquid and solid propulsion launch systems.

The major elements of the agreed strategy for the use and development of national launch systems are:

1. Both DoD and NASA will utilize the Evolved Expendable Launch Vehicle (EELV) for all intermediate and larger payloads for national security, civil, science, and International Space Station cargo re-supply missions in the 5-20 metric-ton-class to the maximum extent possible. As specified in NSPD-40, new commercially-developed launch capabilities will be allowed to compete for these missions if it becomes available.

2. NASA will initiate development of a Crew Launch Vehicle derived from Space Shuttle solid rocket boosters with a new upper-stage for human spaceflight missions in the 25-30 metric-ton-class following retirement of the Space Shuttle in 2010. NASA then plans to develop a new 100 metric-ton-class launch vehicle derived from existing capabilities with the Space Shuttle external tanks and solid rocket boosters for future missions to the Moon.

3. NASA and DoD will jointly pursue a cost-benefit analysis on phasing out the Delta II launch vehicle in favor of EELV to be completed in the coming months.

Additional agreements relative to this topic are:

1. DoD will examine NASA's 100 metric-ton-class lift systems for any future DoD missions that might require such capability.

2. Pending a review of the final report of the Congressionally-directed RAND study into future DoD launch, it is unlikely DoD will endorse the use of a NASA-developed booster as a back-up for EELV due to the significant risk, reliability, and cost of modifications potentially required to DoD's satellites and infrastructure. NASA does not promote the use of a NASA-developed booster as a back-up for EELV.

3. DoD and NASA will commit to explore mutually beneficial cooperation for new upper stage development, advanced materials, other new propulsion technologies, and potential ride-shares on manned and unmanned missions.

We look forward to working with you on the nation's space transportation strategy.

Ronald M. Sega
DoD Executive Agent For Space

Michael D. Griffin
NASA Administrator

cc:
NSC/Steve Hadley
OMB/Josh Bolten
DEPSECDEF/Gordon England
OSD(I)/Dr. Cambone
STRATCOM/General Cartwright, USMC
SPACECOM/General Lord, USAF
NRO/Dr. Kerr

The Office of Science and Technology Policy's *U.S. Space Transportation Policy: Fact Sheet* (January 6, 2005)

The President authorized a new national policy on December 21, 2004, that establishes national policy, guidelines, and implementation actions for United States space transportation programs and activities to ensure the Nation's ability to maintain access to and use space for U.S. national and homeland security, and civil, scientific, and commercial purposes. This policy supercedes Presidential Decision Directive/National Science and Technology Council–4, National Space Transportation Policy, dated August 5, 1994, in whole, and the following portions of Presidential Decision Directive/National Science and Technology Council–8/ National Security Council–49, National Space Policy, dated September 14, 1996, that pertain to space transportation programs and activities: Civil Space Guideline 3b, Defense Space Sector Guideline c, Commercial Space Guideline 5, and Intersector Guideline 2.

Background

For over four decades, U.S. space transportation capabilities have helped the Nation secure peace and protect national security, enabled the Nation to lead the exploration of our solar system and beyond, and increased economic prosperity and our knowledge of the Earth and its environment. Today, vital national security, homeland security, and economic interests are increasingly dependent on United States Government and commercial space assets. U.S. space transportation capabilities—encompassing access to, transport through, and return from space—are the critical foundation upon which U.S. access to and use of space depends.

In accordance with U.S. Space Exploration Policy, dated January 14, 2004, the United States is embarking on a robust space exploration program to advance U.S. scientific, security, and economic interests. A central component of this program is to extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations. The Space Shuttle will be returned to flight as soon as practical, based on the recommendations of the Columbia Accident Investigation Board; used to complete assembly of the International Space Station, planned for the end of this decade; and then retired. A new crew exploration vehicle will be developed to provide crew transportation for missions beyond low Earth orbit.

Access to space through U.S. space transportation capabilities is essential to: (1) place critical United States Government assets and capabilities into space; (2) augment space-based capabilities in a timely manner in the event of increased operational needs or minimize disruptions due to on-orbit satellite failures, launch failures, or deliberate actions against U.S. space assets; and (3) support government and commercial human space flight. The United States, therefore, must maintain robust, responsive, and resilient U.S. space transportation capabilities to assure access to space. In doing so, the United States will emphasize safety in flight and on the ground.

Assuring access to space requires maintaining a viable space transportation industrial and technology base. A significant downturn in the market for commercial launch services has undermined for the time being the ability of industry to recoup its significant investment in current launch systems and effectively precludes industry from sustaining a robust industrial and technology base sufficient to meet all United States Government needs. To assure access to space for United States Government payloads, therefore, the United States Government must provide sufficient and stable funding for acquisition of U.S. space transportation capabilities in order to create a climate in which a robust space transportation industrial and technology base can flourish.

To exploit space to the fullest extent, however, requires a fundamental transformation in U.S. space transportation capabilities and infrastructure. In that regard, the United States Government must capitalize on the entrepreneurial spirit of the U.S. private sector, which offers new approaches and technology innovation in U.S. space transportation, options for enhancing space exploration activities, and opportunities to open new commercial markets, including public space travel. Further, dramatic improvements in the reliability, responsiveness, and cost of space transportation would have a profound impact on the ability to protect the Nation, explore the solar system, improve lives, and use space for commercial purposes. While there are both technical and budgetary obstacles to achieving such capabilities in the near term, a sustained national commitment to developing the necessary technologies can enable a decision in the future to develop such capabilities.

Goal and Objectives

The fundamental goal of this policy is to ensure the capability to access and use space in support of national and homeland security, civil, scientific, and economic interests. To achieve this goal, the United States Government shall:

1. Ensure the availability of U.S. space transportation capabilities necessary to provide reliable and affordable space access, including access to, transport through, and return from space;
2. Demonstrate an initial capability for operationally responsive access to and use of space—providing capacity to respond to unexpected loss or degradation of selected capabilities, and/or to provide timely availability of tailored or new capabilities—to support national security requirements;
3. Develop space transportation capabilities to enable human space exploration beyond low Earth orbit, consistent with the direction contained in U.S. Space Exploration Policy, dated January 14, 2004;
4. Sustain a focused technology development program for next-generation space transportation capabilities that dramatically improves the reliability, responsiveness, and cost of access to, transport through, and return from space, and enables a decision to acquire these capabilities in the future;
5. Encourage and facilitate the U.S. commercial space transportation industry to enhance the achievement of national security and civil space transportation objectives, benefit the U.S. economy, and increase the industry's international competitiveness; and
6. Sustain and promote a domestic space transportation industrial base, including launch systems, infrastructure, and workforce, necessary to meet ongoing United States Government national security and civil requirements.

Implementation of this policy shall be within the overall policy and resource guidance of the President, the availability of appropriations, and applicable law and regulations.

Implementation Guidelines

To achieve the goals of this policy, departments and agencies shall take the following actions:

I. Assuring Access to Space

1. Assured access is a requirement for critical national security, homeland security, and civil missions and is defined as a sufficiently robust, responsive, and resilient capability to allow continued space operations, consistent with risk management and affordability. The Secretary of Defense and the Administrator of the National Aeronautics and Space Administration, as appropriate, are responsible for assuring access to space.
2. The Secretary of Defense shall be the launch agent for the national security sector and shall maintain the capability to develop, evolve, operate, and purchase services for those space transportation systems, infrastructure, and support activities necessary to meet national security requirements.
3. The Administrator of the National Aeronautics and Space Administration shall be the launch agent for the civil sector and shall maintain the capability to develop, evolve, operate, and purchase services for those space transportation systems, infrastructure, and support activities necessary to meet civil requirements, including the capability to conduct human and robotic space flight for exploration, scientific, and other civil purposes. The National Aeronautics and Space Administration shall engage in development activities only for those requirements that cannot be met by capabilities being used by the national security or commercial sectors.
4. For the foreseeable future, the capabilities developed under the Evolved Expendable Launch Vehicle program shall be the foundation for access to space for intermediate and larger payloads for national security, homeland security, and civil purposes to the maximum extent possible consistent with mission, performance, cost, and schedule requirements. New U.S. commercial space transportation capabilities that demonstrate the ability to reliably launch intermediate or larger payloads will be allowed to compete on a level playing field for United States Government missions.
   a. The Secretary of Defense shall maintain overall management responsibilities for the Evolved Expendable Launch Vehicle program and shall fund the annual fixed costs for both launch services providers unless or until such time as the Secretary of Defense, following coordination with the Director of Central Intelligence and the Administrator of the National Aeronautics and Space Administration, certifies to the President that a capability that reliably provides assured access to space can be maintained without two Evolved Expendable Launch Vehicle providers.
   b. Not later than 2010, the Secretary of Defense, the Director of Central Intelligence, and the Administrator of the National Aeronautics and Space Administration shall evaluate the long-term requirements, funding, and management responsibilities for the Evolved Expendable Launch Vehicle system(s) and infrastructure. That evaluation

shall include recommending a proportionate shift of the existing funding responsibility of the Secretary of Defense to reflect any change to the balance between national security and civil missions employing an Evolved Expendable Launch Vehicle.

c. Any department or agency seeking to significantly modify or develop new launch systems derived from the Evolved Expendable Launch Vehicles or its major components, including human rating, shall be responsible for any necessary funding arrangements and shall coordinate with the Secretary of Defense and, as appropriate, the Secretaries of Commerce and Transportation and the Administrator of the National Aeronautics and Space Administration.

5. Before 2010, the United States shall demonstrate an initial capability for operationally responsive access to and use of space to support national security requirements. In that regard, the Secretary of Defense, in coordination with the Director of Central Intelligence, shall:
   a. Develop the requirements and concept of operations for launch vehicles, infrastructure, and spacecraft to provide operationally responsive access to and use of space to support national security, including the ability to provide critical space capabilities in the event of a failure of launch or on-orbit capabilities; and
   b. Identify the key modifications to space launch, spacecraft, or ground operations capabilities that will be required to implement an operationally responsive space launch capability.
6. The Federal space launch bases and ranges are vital components of the U.S. space transportation infrastructure and are national assets upon which access to space depends for national security, civil, and commercial purposes. The Secretary of Defense and the Administrator of the National Aeronautics and Space Administration shall operate the Federal launch bases and ranges in a manner so as to accommodate users from all sectors; and shall transfer these capabilities to a predominantly space-based range architecture to accommodate, among others, operationally responsive space launch systems and new users.

II. Space Exploration

1. The space transportation capabilities necessary to carry out space exploration will be developed consistent with U.S. Space Exploration Policy, dated January 14, 2004.
2. Consistent with that direction, the Administrator of the National Aeronautics and Space Administration shall develop, in cooperation with the Secretary of Defense as appropriate, options to meet potential exploration-unique requirements for heavy lift beyond the capabilities of the existing Evolved Expendable Launch Vehicles.
   a. These options will emphasize the potential for using derivatives of the Evolved Expendable Launch Vehicles to meet space exploration requirements. In addition, the Administrator shall evaluate the comparative costs and benefits of a new dedicated heavy-lift launch vehicle or options based on the use of Shuttle-derived systems.

b. The Administrator and the Secretary shall jointly submit to the President a recommendation regarding the preferred option to meet future heavy-lift requirements. This recommendation will include an assessment of the impact on national security, civil, and commercial launch activities and the space transportation industrial base.

III. Transformation of Space Transportation Capabilities

1. The United States shall sustain a focused technology development program for next-generation space transportation capabilities to transform U.S. access to and use of space. In that regard, the Secretary of Defense and the Administrator of the National Aeronautics and Space Administration, in cooperation with industry as appropriate, shall:
   a. Within two years of the date of this policy, develop the requirements, concept of operations, technology roadmaps, and investment strategy for next-generation space transportation capabilities with the objective of dramatically improving the reliability, responsiveness, and cost of Earth-to-orbit space transportation for deployment of spacecraft and other payloads in Earth orbit, exclusive of human space flight; and
   b. Pursue research and development of in-space transportation capabilities to enable responsive space transportation capabilities and the transformation of the Nation s ability to navigate in space. These efforts shall include, but not be limited to: automated rendezvous and docking, and the ability to deploy, service, and retrieve payloads or spacecraft in Earth orbit. The Administrator of the National Aeronautics and Space Administration, in cooperation with the Secretary of Energy and other departments and agencies as appropriate, shall pursue research and development of space nuclear power and advanced propulsion technologies to more quickly, affordably, and safely expand the reach of exploration into the solar system and beyond.

IV. Commercial Space Transportation

1. The United States Government is committed to encouraging and facilitating a viable U.S. commercial space transportation industry that supports U.S. space transportation goals, benefits the U.S. economy, and is internationally competitive. Toward that end, United States Government departments and agencies shall:
   a. Purchase commercially available U.S. space transportation products and services to the maximum extent possible, consistent with mission requirements and applicable law;
   b. Provide a timely and responsive regulatory environment for licensing commercial space launch and reentry activities;
   c. Maintain, subject to periodic review and the competitiveness of U.S. industry, the liability risk-sharing regime for U.S. commercial space transportation activities set forth in the Commercial Space Launch Act, as amended (49 USC, Subtitle IX, Chapter 701), including provisions for indemnification by the United States Government;

d. Refrain from conducting activities with commercial applications that preclude, deter, or compete with U.S. commercial space transportation activities, unless required by national security;
e. Involve the U.S. private sector in the design and development of space transportation capabilities to meet United States Government needs;
f. Provide stable and predictable access to the Federal space launch bases and ranges, and other government facilities and services, as appropriate, for commercial purposes on a direct-cost basis, as defined in the Commercial Space Launch Act, as amended (49 USC, Subtitle IX, Chapter 701). The United States Government reserves the right to use such facilities and services on a priority basis to meet national security and critical civil mission requirements;
g. Encourage private sector and state and local government investment and participation in the development and improvement of space infrastructure, including non-Federal launch and reentry sites; and
h. Provide for the private sector retention of technical data rights in acquiring space transportation capabilities, limited only to the extent necessary to meet United States Government needs.

2. The Secretary of Transportation shall license and have safety oversight responsibility for commercial launch and reentry operations and for operation of non-Federal launch and reentry sites, as set forth in the Commercial Space Launch Act, as amended (49 USC, Subtitle IX, Chapter 701), and Executive Order 12465. The Secretary of Transportation shall coordinate with the Secretary of Defense, the Administrator of the National Aeronautics and Space Administration, and other United States Government departments and agencies, as appropriate.
   a. The Secretaries of Transportation and Defense shall establish common public safety requirements and other common standards, as appropriate, taking into account launch vehicle type and concept of operation, for launches from Federal and non-Federal launch sites. The Secretaries of Transportation and Defense shall coordinate these requirements with the Administrator of the National Aeronautics and Space Administration and other departments and agencies as appropriate.

3. The Secretaries of Commerce and Transportation shall encourage, facilitate, and promote U.S. commercial space transportation activities, including commercial human space flight.

V. U.S. Space Transportation Industrial and Technology Base

1. A viable domestic industrial and technology base is the foundation of a successful U.S. space transportation capability and is critical to assuring access to space for national security and civil purposes. To assure access to space and ensure national security and civil space transportation needs will continue to be met in the future:

a. United States Government payloads shall be launched on space launch vehicles manufactured in the United States, unless exempted by the Director of the Office of Science and Technology Policy, in consultation with the Assistant to the President for National Security Affairs.
   - This policy does not apply to use of foreign launch vehicles on a no-exchange-of-funds basis to support the following: flight of scientific instruments on foreign spacecraft, international scientific programs, or other cooperative government-to-government programs. This policy also does not apply to the use of foreign launch vehicles to launch United States Government secondary scientific payloads for which no U.S. launch service is available.
   - The proposed use of a non-U.S.-manufactured launch vehicle will be subject to interagency coordination as early in the program as possible and prior to the sponsoring department's or agency's request for authority to negotiate and conclude an agreement. Interagency coordination will take into account national security and foreign policy concerns, civil and scientific interests, and the performance, availability, and economic and budgetary considerations associated with use of the proposed launch vehicle.

b. The use of foreign components or technologies, and the participation of foreign governments and entities, in current and future U.S. space transportation systems is permitted consistent with U.S. law and regulations, as well as nonproliferation, national security, and foreign policy goals and commitments and U.S. obligations under the Strategic Arms Reduction Treaty, Intermediate Nuclear Forces Treaty, and the Missile Technology Control Regime. Such use or participation will not be permitted where it could result in critical national security or civil space launches being jeopardized by delays or disruptions in receipt of foreign-produced systems, components, technology, or expertise.

VI. Nonproliferation and Use of Excess Ballistic Missiles

1. In order to prevent the proliferation of missile technology and to limit the adverse impact of use of excess ballistic missiles on U.S. space transportation capabilities:

a. Excess U.S. ballistic missiles shall either be retained for government use or destroyed. United States Government agencies may use such assets to launch payloads into orbit on a case-by-case basis, with the approval of the Secretary of Defense, when the following conditions are met: (1) the payload supports the sponsoring agency's mission; (2) such use is consistent with the obligations of the United States under treaties and other international agreements to which the United States is a party, including the Missile Technology Control Regime guidelines, the Strategic Arms Reduction Treaty, and the Intermediate Nuclear Forces Treaty; and (3) the sponsoring agency certifies that such use results in a cost savings to the United States Government compared to the use of available commercial launch services that would also meet mission requirements, including performance, schedule, and risk, and limits the impact on the U.S. space transportation industry;

b. The United States Government encourages other nations that possess excess ballistic missiles to limit their use to government purposes only or destroy them. The United States Government will consider on a case-by-case basis requests from U.S. companies to use foreign excess ballistic missiles for space launch purposes. Any such use must be in conformity with arms control agreements, U.S. nonproliferation policies, U.S. technology transfer policies, and the Missile Technology Control Regime guidelines; and

c. The United States Government shall consider on a case-by-case basis requests to launch foreign space transportation systems in the United States for commercial purposes, including exhibitions and demonstrations. Any such use shall be subject to interagency coordination and must be in conformity with U.S. national security and foreign policy interests, arms control agreements, U.S. nonproliferation policies, U.S. technology transfer policies, the Missile Technology Control Regime guidelines, and launch and re-entry licensing regulations.

APPENDIX C

National Security Space Launch Panel Members

The Panel unanimously agree with this report, and a signature sheet is on file.

Forrest McCartney, Chair

Forrest S. McCartney, Lt Gen, USAF (Ret.), served 35 years in Air Force and space programs; Director of NASA Kennedy Space Center; consultant to industry; and Vice President for Atlas and Titan Launch Operations, Lockheed Martin Corporation. Lt Gen McCartney has 50 years of space-related activities.

Lyle Bien

Lyle G. Bien, VADM, USN (Ret.), served 31 years on active duty flying carrier-based fighter aircraft, commanded the USS *Nimitz* Battle Group during the 1996 Taiwan missile crisis. He commanded the Naval Space Command, Dahlgren, Virginia, and was Deputy Commander U.S. Space Command, Vandenberg AFB, where he led the Senior Warfighter Forum that conceived the Wideband Gapfiller satellite. VADM Bien is currently a consultant to industry and the U.S. government, primarily in the fields of space-based communications and missile defense.

Delma Freeman

Delma C. Freeman, Jr., served 42 years in with NASA, specializing in aerodynamics, aerothermodynamics, and launch and entry vehicle systems analysis. He was Director of NASA's Langley Research Center; consultant to industry; fellow of the American Institute of Aeronautics and Astronautics; and member of the International Academy of Astronautics. Mr. Freeman has 46 years experience in space-related subjects.

Rick Larned

Rick Larned, Brig Gen, USAF (Ret.), served 26 years in Air Force and NRO space programs; cochair of Titan IV K-11 accident investigation board; Air Force Space Command Deputy Director of Operations; NRO Director of SIGINT programs, IMINT programs, and budget; and consultant to industry. Brig Gen Larned has 33 years experience in space-related activities.

Leslie Lewis

Leslie Lewis, Ph.D. (history and economics, University of California, Los Angeles), Deputy Director, Strategic Intelligence Management and decision-making directorate, Center for Intelligence Research and Analysis; senior researcher, the RAND Corporation.

T. K. Mattingly

T. K. Mattingly, RADM, USN (Ret.), Apollo; Shuttle; Director, Space and Sensor Programs, USN; Vice President, Atlas Programs, General Dynamics; Vice President, Reusable Launch Vehicles, Lockheed Martin; President, Rocket Development Company; and Director, Space Enterprise, Systems Planning and Analysis.

Jimmey Morrell

Jimmey R. Morrell, Maj Gen, USAF (Ret.), served 24 years of Air Force service; intelligence officer; Minuteman missile combat commander; White House senior policy analyst; Assistant for Space to the Secretary of the Air Force; Air Force Space Command Director of Space Operations; Commander, 2nd Space Wing; Commander, 9th Space Division; Commander, 45th Space Wing; Senior Vice President, GRC International; and consultant to industry. Maj Gen Morrell has 26 years experience in space-related activities.

Chet Whitehair

Chester Whitehair, Vice President (Ret.) Space Launch Operations, Aerospace Corporation; 35 years service at Aerospace working on space programs in support of the Air Force, DoD, NRO, and NASA; consultant to government and industry. Mr. Whitehair has 46 years experience of space-related engineering and technical management activities supporting more than 200 space launches.

RAND Corporation

Peter A. Wilson, Executive Director
William Williams, Senior Defense Analyst
Thor Hogan, Senior Political Scientist
David Ortiz, Senior Researcher
Charles J. Bushman, Research Assistant
Estelle Beemer, Project Associate
Jean Preston, Administrative Assistant

Reviewers

David Frost, VADM, USN (Ret.), former Deputy Commander, U.S. Space Command, and Vice Commander, NORAD
A. Thomas Young, former Chairman, Joint Task Force on Acquisition of National Security Space Programs

APPENDIX D

National Security Space Launch Panel Contacts and Speakers

Military

Maj Gen Roger W. Burg, Director of Strategic Security, Office of the Deputy Chief of Staff for Air, Space and Information Operations, Plans and Requirements, Headquarters U.S. Air Force, Washington, D.C.

Maj Gen Craig R. Cooning (Ret.), Director, Space Acquisition, Office of the Under Secretary of the Air Force—"The Moorman Study & New Spacelift Vehicles."

Col Hal Hagemeier (Ret.), National Security Space Office—"NSSO Responsive Space Operations Architecture"

- **Cdr Edward Kneller**, National Security Space Office
- **J. Lynn K. "Cork" Corcoran**, Deputy, Space and Communications Branch, Chief of Naval Operations

Lt Gen Michael A. Hamel, Commander, Space and Missile Systems Center, Air Force Space Command, Los Angeles Air Force Base, California.

Col Dennis Hilley, Deputy Director, Space Programs, ASD NII (DoD—discussion on EELV and "The New Launch Joint Venture & Future Launch Needs"

Dr. Steven Huybrechts, Director Space Programs, ASD (NII) (DoD)—"NASA-DoD Agreement on Launch"

Lt Gen C. Robert Kehler, Deputy Commander, U.S. Strategic Command, Offutt Air Force Base, Nebraska (via telephone conference)

Col James M. Knauf, Deputy Director, Directorate of Space Acquisition (SAF/USA).

VADM James D. McArthur, Jr., Commander, Naval Network Warfare Command—"Naval Space Requirements and Access to Space Issues."

Maj Gen Mark D. Shackelford, Director of Requirements, Air Force Space Command—"AFSPC Space Launch Requirements and Strategy"

Col Thomas Shearer, Planning Integration Division, National Security Space Office (DoD)—"National Security Space Capability and Integration"

Col Pamela L. Stewart, Air Force Space Command Headquarters, Directorate of Requirements—"ORS Operationally Responsive Space," "AFSPC Operational Requirements for Assured Access to Space, and Future Concepts"

Lt Col Chris Warack, USAF, Office of the Deputy Secretary of Defense for Industrial Policy—"Industrial Base Assessment"

Col Edward G. Zakrzewski, Director (now retired), Office of Space Launch, National Reconnaissance Office—discussion on launch requirement.

- **Col James O. Norman**, USAF, Deputy Director (now Director), Office of Space Launch, National Reconnaissance Office
- **Col John Stizza**, Office of Space Launch, National Reconnaissance Office

Government

Dr. Stephen A. Cook, Director of Exploration Launch Office, NASA Marshall Space Flight Center—"The Challenge of SDV and CEV"

Madelyn Creedon, Minority Counsel, Committee on Armed Services, U.S. Senate—discussions on space launch, "Buy 3" issues, and update on EELV and "Buy 3" contracts

Gil Klinger, Director of Space Policy, Defense Policy and Arms Control Directorate, National Security Council Staff (now Assistant Deputy Director of National Intelligence for Technical Collection Means)—"National Space Transportation Policy and Associated Issues Discussion"

Dr. Michael F. Lembeck, Exploration Systems Mission Directorate, Requirements Division (NASA)—"ISS Options/ESMD Transportation AoA"

James R. Martin, Chief Force Structure and Investment, Office of Management and Budget—discussion of space transportation and policy

Richard W. McKinney, Deputy Director of Space Acquisition (now Director) (USAF), discussion of space transportation and policy

Dr. Scott Pace, Associate Administrator, Policy Analysis and Administration, NASA—"Directives and Actions from the NASA Administration" and "The Exploration Systems Architecture Study"

John Remen, Space and Missile Propulsion Division, Air Force Research Lab, Air Force Material Command (USAF)—"Air Force Planning for Assured Access to Space"

Patty Grace Smith, Associate Administrator for Commercial Space Transportation, Federal Aviation Administration—"Commercial Space Launches"

Dr. Steven H. Walker, FALCON Program Manager, Tactical Technology Office, Defense Advanced Research Projects Agency (DoD)—"FALCON Program Overview"

Industry

Dr. Mark J. Albrecht, President, International Launch Services—"State of Launch Industry"

Bretton Alexander, Vice President for Government Relations, Transformational Space Corporation—"Simple, Reliable Easily Manufactured Booster"

David A. Cavossa, Executive Director, Satellite Industry Association—"State of the Satellite Industry Report"

James Harvey, Director, NASA Advanced Space Programs, Boeing Launch Services—"2005 RAND Study, Assured Access to Space"

- **Frank Slazer**, Director, Civil Space Programs, Boeing Launch Services
- **Gene Collins**, Senior Specialist, Boeing Corporation
- **Dr. Andrew Aldrin**, Vice President, Boeing Launch Services

James Elinthorpe, Boeing, Sea Launch Market discussion

Joe Fragola, principal scientist, SAIC (now with Valador Inc.)—"Launch Risk Realities"

Michael C. Gass, Vice President and General Manager, Lockheed Martin Space Systems Company (appointed President and CEO, United Launch Alliance)—"Status of United Launch Alliance Joint Venture with Boeing and Lockheed"

- **Dr. George Sowers**, Director, Business Development and Advanced Programs, Space Transportation, Lockheed Martin Space Systems Company
- **Ray Ernst**, Lockheed Martin
- **Daniel J. Collins**, Vice President, Boeing Expendable Launch Systems (appointed COO, United Launch Alliance)

John E. "Ted" Gordon, Senior Vice President, Washington, D.C. Operations, Alliant TechSystems Inc.—"Solid Propulsion Systems"

- **Charlie Precourt**, Alliant TechSystems Inc.
- **Michael Kahn**, Alliant TechSystems Inc.
- **Ron D. Dittemore**, Senior Vice President and President, Alliant TechSystems Inc.
- **Dr. Tony Castrogiovanni**, Alliant TechSystems Inc.
- **Kevin Jackson**, Washington Office, Alliant TechSystems Inc.

Dr. Dan Heimerdinger, Executive Vice President and Chief Technology Officer, Valador Inc.—"Shuttle Decommissioning Analysis"

John Kohut, Program Manager, Raytheon Company—"Integrated Space Exploration"

- **Steve Vamvakis**, Chief Engineer, Missile Systems, Raytheon Company

Clayton Mowry, President, Arianespace Inc., North American—"Launch Solutions"

Elon Musk, CEO and CTO, Space Exploration Technologies (SpaceX)—"Being the Southwest Airlines of Space"

Dr. Earl Renaud, Chief Operating Officer, TGV, "Rockets and Affordable Access to Near Space"

- **Kent Ewing**, Chairman, TGV

Ron Samborsky, Vice President of Strategy, Aerojet Corporation—"An Appreciation of the Space Launch Industry" and "Future of Military Space Launch"

- **Julie Van Kleeck**, Vice President Space Programs, Aerojet Corporation
- **Katharine Robinson**, Executive Director, Strategic Systems and Advanced Structures, Aerojet Corporation
- **Donald H. Brownlee**, Vice President Washington Operations, Aerojet Corporation

- **Charles Abernethy**, Director Business Development, Military Space and Hypersonics, Aerojet Corporation

Dr. David W. Thompson, Chairman and CEO, Orbital Sciences Corporation—"Launch Vehicle and Satellite Outlook"

- **Dr. Antonio L. Elias**, Executive Vice President and General Manager, Advanced Programs Group, Orbital Sciences Corporation

Wilber C. Trafton, Kistler Aerospace Corporation and Will Trafton and Associates—"K-1 Reusable Aerospace Vehicle: Program Status & Capability & the Future Is Reusable Aerospace Vehicles"

- **Debra Facktor Lepore**, Vice President, Business Development and Strategic Planning, Kistler Aerospace Corporation
- **Dean Misterek**, System Engineering Manager, Kistler Aerospace Corporation

Byron Wood, President, Pratt & Whitney Rocketdyne—"Future Launch Vehicle Requirements"

- **Joe Adams**, Vice President and General Manager, Pratt & Whitney Rocketdyne
- **Robert Anderson**, Washington Operations, Pratt & Whitney Rocketdyne

Academic/Private

Chris Andrews, Booz Allen Hamilton—"Science & Technology Issues"

Philip Antón, Director of Acquisition and Technology Policy Center, National Defense Research Institute, RAND Corporation

Dr. Wanda Austin, Air Force Scientific Advisory Board (Senior Vice President for the National Systems Group, Aerospace Corporation)—"Operationalizing Space Launch"

Bruce Bartos, Aerospace Corporation—"EELV Human Rating"

Stan Goldberg, Universal Technologies Corporation—"Future Joint Planning"

Dr. Henry R. Hertzfeld, Research Professor of Space Policy and International Affairs, Elliott School of International Affairs, George Washington University—"Launch Vehicle Economics" and "Launch Vehicles-Implications of Changing Economic and Policy Trends for NASA"

Gen Thomas S. Moorman, Jr. (Ret.), USAF, Vice President, Booz Allen Hamilton, (discussion conducted in his office with some Panel members)

Liam Sarsfield, Space Programs Consultant—"Exploration Vision: History & Challenges"

Russ Shaver, Senior Analyst, RAND Corporation—"Operationally Responsive Space"

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