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Headquarters
Air Force
Space Command
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AFSPC/PA
150 Vandenberg St. Ste 1105
Peterson AFB, CO 80914
Telephone: (719) 554-3978
Fax: (719) 554-6013

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Cover: Atlas V, Evolved Expendable Launch Vehicle designed to improve space launch operability and standardization.
Source: Earth with Sunburst, background image, National Aeronautics and Space Administration

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Introduction

Assured Access to Space in a Competitive World

General Kevin P. Chilton
Commander, Air Force Space Command

"It is difficult to say what is impossible, for the dream of yesterday is the hope of today and reality of tomorrow."

- Dr. Robert Goddard

Each new issue of the *High Frontier* journal sets the bar higher for quality and critical thinking on issues of importance to the National Security Space (NSS) enterprise. This issue offers informed perspectives on the state of our launch capabilities as well as many other topics. The "Warfighter Focus" section contains informative articles on topics ranging from the enhancement of joint space operations to the command and control of small satellites. We have compiled an impressive list of authors, providing historical insight, thoughts on current operations, as well as suggestions for our way ahead. As always, our goal is to stimulate thought across the NSS enterprise, embracing a multitude of diverse opinions. You may have also noticed the "*High Frontier* is going digital" announcement on the front cover. This effort will make the journal more reader friendly while reducing the costs associated with publishing more than 12,000 copies. We encourage everyone to take a look at our on-line site and if you read an interesting article, send the link (http://www.af.mil/subscribe/) to a co-worker or friend.

The rockets we launch into space carry with them the communication, weather, surveillance, navigation, and other national assets which are integral to our national security as well as our economy. For these critical spacecraft, the first few moments after liftoff are both the most exciting and the most dangerous. If something is going to go wrong, it most likely will happen on the way into orbit. For that reason, space launch is a business we pay close attention to and it is also an area where we set high standards.

Operationally, we provide space support by flying out our legacy boosters while successfully bringing on our Evolved Expendable Launch Vehicle (EELV) class of launch systems. With an unprecedented streak of 14 operational successes in a row, our EELVs are well on the way to proving their worth to our Nation. Today, Air Force Space Command (AFSPC) has successfully launched 47 national security payloads in a row. This impressive streak dates back to the Broad Area Review, undertaken in response to multiple launch failures in the late 1990s. It is also a direct result of the launch experts who provide technical expertise, operational savvy, and mission assurance. Without question, these professionals are a national asset and we are doing everything in our power to attract, develop, and retain as many of them as possible. Our future success depends on it.

While we continue to develop more traditional satellite constellations, we also have an eye on the future and smaller, more tactical spacecraft. Dubbed "responsive space," our goal is not to supplant legacy or EELV operations. As technology improves we aim to pursue the development of smaller satellites, opening up the possibility of smaller classes of boosters. The Minotaur program and tactical satellites are perfect examples of this. There are three key missions for responsive lift being discussed. First, use responsive operations in augmenting surveillance and reconnaissance platforms in response to the needs of a combatant commander. Second, responsive operations may have utility in replacing space assets that have been disabled by attack or natural phenomenon. This is not meant to imply a one-for-one replacement strategy. A quick launch replacement capability would only provide the most vital capabilities of the asset in question. These capabilities would be enough to meet combatant commander requirements until the launch of a fully capable replacement. Finally, responsive space holds promise to enhance Space Situational Awareness.

Since the early 1990s we have continued to see a dramatic increase in the use and integration of space into military and humanitarian operations. Our combatant commanders rely on the asymmetric advantage our space capabilities bring to the fight, and so we must guarantee access to the space domain. For us, that translates into a steadfast commitment to the EELV program while simultaneously searching out innovative, responsive options. With your help, the space and missile experts at AFSPC, will continue to guarantee assured access to space.

General Kevin P. Chilton (BS, Engineering Science, USAFA; MS, Mechanical Engineering, Columbia University) is Commander, Air Force Space Command, Peterson AFB, Colorado. He is responsible for the development, acquisition and operation of the Air Force's space and missile systems. The general oversees a global network of satellite command and control, communications, missile warning and launch facilities, and ensures the combat readiness of America's intercontinental ballistic missile force. He leads more than 39,700 space professionals who provide combat forces and capabilities to North American Aerospace Defense Command and US Strategic Command.

General Chilton flew operational assignments in the RF-4C and F-15 and is a graduate of the US Air Force Test Pilot School. He conducted weapons testing in various models of the F-4 and F-15 prior to joining the National Aeronautics and Space Administration in 1987. General Chilton is a command-rated astronaut and test pilot with more than 5,000 flying hours. He has flown on three space shuttle missions and served as the Deputy Program Manager for Operations for the International Space Station.

The general has served on the Air Force Space Command Staff, the Joint Staff, the Air Staff, and commanded the 9th Reconnaissance Wing. Prior to assuming his current position, he was Commander, 8th Air Force and Joint Functional Component Commander for Space and Global Strike.

Among his many awards, General Chilton has been awarded the Distinguished Service Medal, the Distinguished Flying Cross, and the NASA Exceptional Service Medal. At his promotion ceremony 26 June 2006, he became the first astronaut to reach the rank of four-star general.

Assured Access to Space

General James E. Cartwright
Commander, US Strategic Command

"The 2006 Unified Command Plan appointed USSTRATCOM as the single point of contact for military space operational matters. With our new UCP responsibilities toward space, assured access to space is one of the most important issues facing the Command."

- General James E. Cartwright, Commander, US Strategic Command

The first era of the space age was one of experimentation and discovery. Today, the United States is on the threshold of a new era of space, devoted to mastering operations in space. Space-based technology is revolutionizing major aspects of commercial and social activity, and space-related capabilities help national leaders implement American foreign policy and, when necessary, use military power in ways never before employed.

In the future, the US will conduct operations to, from, in and through space in support of its national interests both on the Earth and in space. The US must have the same capabilities in space as it does on the land, in the air, and at sea to defend its assets against hostile acts and to negate the hostile use of space against US interests.

In other words, we must have *Assured Access to Space* to carry out the Unified Command Plan responsibilities assigned to the United States Strategic Command (USSTRATCOM).

USSTRATCOM's approach to assured access to space contains six major elements:

Operationally Responsive Acquisition

This is an energetic topic within national circles and has not yielded any one single way ahead. What is clear is that assured access to space is held back when it takes literally decades to acquire new systems that are often obsolete before they are launched. Assured access to space is also threatened when the cost of these systems is so great that we cannot afford more than one or two units of a space capability. Limited systems are vulnerable to loss through either natural or man-made threats.

There are four major goals of operationally responsive acquisition:

Reducing Development and Deployment Time and Cost

The Department of Defense is leveraging the best commercial practices available. For example, the industry trend has been to take advantage of advances in miniaturization, automation, and materials to create more capable smallsats, microsats, and even nanosats. Smaller size allows for multiple satellites to be launched on a single small booster. Defense Advanced Research Projects Agency recently launched an experimental project to test whether the advanced technologies embedded in two miniature satellites and a new upper stage kick motor can operate through the rigors of spaceflight. The results of this project are eagerly anticipated.

Capitalizing on Emerging and Innovative Capabilities

Continue the process of integrating the products of high-risk exploratory work done in the scientific and technical world into operational systems. Too often, successful technology demonstrations do not lead to increased operational capabilities because no planning was conducted for the transition. The Micro-Satellite Technology Experiment, or MiTex for short, will investigate and demonstrate advanced, lighter, off-the-shelf space technologies. This demonstration will give military planners real-life experience to draw upon when designing new constellations.

Connecting Space to the User

Space systems must not exist in a stovepipe, but must be relevant to the Joint Force operational commander and adaptable to joint warfare. Project IRIS—Internet Protocol Routing In Space—is another Advanced Concept Technology Demonstration currently underway to literally take the Internet into space. This means a soldier in the field will be far more able to send and receive real-time information and knowledge.

Responding to the Urgent Need

An improved mechanism is needed for delivering effects to joint warfare in response to an urgent or unanticipated need. The one fact we can count on is that warfighters cannot always predict exactly how and when space capabilities will be needed, so flexibility and adaptability must be incorporated into space planning. The national space partners are working to develop tactical satellites—TACSATs—to demonstrate that operationally relevant, rapidly deployable spacecraft can support military operations anywhere on Earth. The selectable payloads will be tailored to a specific area or effect. These payloads must be under direct control of the Joint Task Force commander, making space assets an organic part of the force.

Launch Infrastructure

A balanced mix of launch-on-demand, store-on-orbit, and launch-on-schedule systems is required, as well as the ability to surge in response to the changing battlefield environment. Launch systems must include more than just the physical hardware of the boosters, but also all the supporting equipment and personnel expertise. Launch flexibility becomes restrictive when key personnel and equipment assets are tied to a single launch facility. The ability to launch and operationalize a satellite in a matter of hours or days instead of weeks is vital to our national security interests.

Flexible Command and Control Architecture

Technological advancements alone are not the solution. They must be met with an appropriate culture and delivered to trained warfighters. USSTRATCOM has created a Joint Functional Component Command for Space and appointed a commander who is charged with executing command and control of space assets and with preparing for a new paradigm of responsive space capabilities. At the warfighter level, space operators are now directly participating in technology programs, building concept of operations and developing tactics, techniques and procedures for operational employment.

The operationally responsive space concept requires developing processes for theater commanders to directly task supporting space assets. Allowing the theater to manage space assets will result in some institutional resistance, but it increases the speed and flexibility of space support to the warfighter. Those who make decisions and maneuver faster will win. The speed of decision-making is an asymmetric advantage of the US military and can be enabled through the space domain.

Risk Management

Space is a harsh environment and early space advances required considerable technological sophistication. The high cost and low density of military systems naturally leads to a low tolerance for risk. It is time to reconsider this philosophy. There is always risk; the key is the ability to understand, quantify, and manage that risk. Better tools are needed to evaluate our systems under stress—whether natural or man-made—enabling leaders to make choices on where they can accept risk. The new approach to *Assured Access* not only recognizes failures are possible but also assumes we can rapidly assess their impact and can react appropriately.

The NS-7C/D Global Positioning System (GPS) is a constellation of orbiting satellites that provides navigation data to military and civilian users worldwide.

Integration

Every military member and every platform is a sensor. Sensor capability across all mission areas must be shared. Databases must be open to the joint warfighting community, regardless of the source being terrestrial or space-based. Access to data is critical to joint warfighting and truly makes the sum of the whole greater than the sum of the individuals. The primary functions of capabilities operated in space are to collect (e.g., intelligence, surveillance, and reconnaissance), broadcast (e.g., global positioning system), and move (e.g., satellite communications [SATCOM]) information vital to Joint Force decision-making. This requires a seamless integration of space contributions into all the systems the joint warfighters employ. The integration process must be considered at the start, beginning with the conception of new space systems.

Cape Canaveral AFS, Florida, 19 January 2006. An Atlas V vehicle provided by International Launch Services (ILS) successfully propelled NASA's New Horizons spacecraft on a 9-and-a-half-year mission to Pluto.

Warrior Mindset

Finally, space systems are weapon systems supporting warfighting requirements and utilities provided as a service. For example, there was a time when SATCOM interference was ignored if it was not significantly degrading the service on a channel. Today, such interference is considered potentially hostile and investigated until we can rule out hostile intent.

To truly assure access to space, improved space situational awareness is needed to detect, characterize, locate, and mitigate all sources of interference or degradation.

More importantly, space systems exist for a purpose, and that purpose ties directly to the warfighting demands of a Joint Force commander. Efficient operations in peacetime are important, but not the central issue. The warfighters need these systems to be there for them under stress conditions. Our adversaries have the capability—in some cases have already employed capabilities—to deny US access to space. Adversaries already recognize the importance of our space systems to joint warfighting capability, and will attempt to deny them at the most inopportune time. To truly assure access to space, improved space situational awareness is needed to detect, characterize, locate, and mitigate all sources of interference or degradation. This requires wartime reserve modes, contingency plans for outages, the ability to re-route services (across all platforms), to reconstitute or augment existing capabilities, or to neutralize the source of the disruption.

This holistic view of *Assured Access to Space* is ambitious but necessary. The US cannot afford to wait for major technological breakthroughs that may yet be decades in the future. Current capability gaps need to be addressed today, leveraging existing technology and better employing existing weapon systems. US reliance on our space-based architecture is obvious to friend and foe alike. It is our freedom of action in space, at a time and place of our choosing, that must be assured.

Carleton Bailie/Boeing

Cape Canaveral AFS, Florida, 20 November 2004. A Boeing Delta II rocket delivered to orbit a NASA spacecraft that will monitor the afterglow of explosions in space. The Swift observatory was launched by a Delta II 7320-10C vehicle.

General James E. Cartwright (MA, National Security and Strategic Studies, Naval War College, Newport, Rhode Island) is Commander, United States Strategic Command, Offutt AFB, Nebraska. He is responsible for the global command and control of US strategic forces to meet decisive national security objectives. USSTRATCOM provides a broad range of strategic capabilities and options for the President and Secretary of Defense.

Command mission areas include full-spectrum global strike, space operations, computer network operations, Department of Defense information operations, strategic warning, integrated missile defense, and global Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR), combating weapons of mass destruction, and specialized expertise to the joint warfighter.

General Cartwright was commissioned a second lieutenant in the Marine Corps in November 1971. He attended Naval Flight Officer training and graduated in April 1973. He attended Naval Aviator training and graduated in January 1977. He has operational assignments as an NFO in the F-4, and as a pilot in the F-4, OA-4, and F/A-18. Some of the general's staff assignments include: Director for Force Structure, Resources and Assessment, J-8 the Joint Staff; Deputy Aviation Plans, Policy, and Budgets Headquarters, US Marine Corps; and Assistant Program Manager for Engineering, F/A-18 Naval Air Systems Command.

General Cartwright was named the Outstanding Carrier Aviator by the Association of Naval Aviation. He graduated with distinction from the Air Command and Staff College, Maxwell AFB, Alabama. He was selected for and completed a fellowship with Massachusetts Institute of Technology in 1994.

Senior Leader Perspective

Framing the Assured Access Debate: A Brief History of Air Force Space Launch

General Thomas S. Moorman, Jr., USAF, retired
Vice President, Booz Allen Hamilton

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.[1]

Introduction

While the term "assured access to space" was coined in 1983, the concept traces its roots to the earliest days of the Air Force's involvement in space. Understanding our Nation's current approach to assured access requires some appreciation of the evolution of our Air Force launch capabilities and the major events that have influenced those capabilities. In this article, I will pay special attention to two studies. The first, the Space Launch Modernization Plan (SLMP) was completed in 1994 and ultimately led to the creation of the Evolved Expendable Launch Vehicle (EELV) program. The second, the Assured Access Space Study, was completed two years ago and helped frame the debate on whether the government should maintain one or two major launch vehicle providers.

Origins of Assured Access

The story begins at the dawn of the Space Age. In 1955, President Dwight D. Eisenhower declared the United States' intent to launch a scientific satellite as part of the International Geophysical Year (IGY) (1957-1958), with the intent to establish the principles of "freedom of space" and "international overflight." Consistent with the civilian mission orientation of the IGY, the US selected the "non-military" Naval Research Laboratory's Project Vanguard launch vehicle over two military ballistic missile-derived solutions (the Army Redstone's Jupiter booster and the Air Force's Atlas booster). Ultimately, the Vanguard program had schedule and budget problems.[2] As a consequence the Soviets beat us to space by orbiting Sputnik I in October 1957.

The launch of Sputnik created a US national crisis. Sputnik was an 184 lb. instrumented package launched via a rocket booster weighing nearly four tons, whereas Vanguard's satellite weighed less than four pounds.[3] This demonstrated the Soviets were technologically sophisticated enough to deploy both operating spacecraft and an intercontinental ballistic missile (ICBM) force.

Over the next few years, the US reaction to Sputnik resulted in the establishment of the National Aeronautics and Space Administration (NASA) in the fall of 1958, the creation that same year of the Advanced Research Projects Agency (the forerunner of the Defense Advanced Research Projects Agency), and continued competition between the services for supremacy in the space and ballistic missile missions.[4] In the fall of 1959, Secretary of Defense Neil H. McElroy assigned the Air Force responsibility for the development, production, and launch of space boosters (as well as payload integration).[5] This decision was the direct result of a concerted effort by Air Force leadership, spearheaded by Maj Gen Bernard A. Schriever, to acquire all or part of the space mission.

The Air Force's space boosters or expendable launch vehicles (ELV) were derived from Atlas, Titan, and Thor long-range and intermediate-range ballistic missile development efforts ongoing under General Schriever since 1954.[6]

- Atlas was conceived as an intercontinental ballistic missile, but became the first large American space booster in late 1958. Atlas would go on to have a short career as an ICBM, but a long one as a space launcher. Since 1957, Atlas has flown nearly 600 times in different configurations.[7]
- The two-stage Titan ICBM was originally built as a backup to the Atlas missile. Development forked into two paths, one supporting the crewed Gemini program, while the other provided an ICBM capability for 20 years. When the Titan missiles were retired in the mid-1980s, some of them were refurbished and converted to space launch vehicles. The last Titan vehicle was launched in 2005, making it the 368th vehicle in this family.[8]
- The Delta family began with roots in Thor and Vanguard in the late 1950s and continues to serve as a space launcher today. Delta began as a small launcher, originally capable of only lifting 150 lbs. to geosynchronous transfer orbit, and then evolved to a more powerful medium-lift launcher. Over 700 vehicles have been built in Delta's four decades of service.[9]

Although by the early 1970s Atlas, Titan, and Delta had become reliable ELVs, the country soon pursued a more ambitious means to space. The debate surrounding the future of manned space programs in the post-Apollo, post-Vietnam budgets era was settled when the Nixon Administration chose to build the Space Transportation System more commonly referred to as the Space Shuttle. Once initial design and development were completed, President Jimmy Carter, Jr., decided that only the Space Shuttle would launch US satellites into space. The rationale for this decision was driven by cost-per-flight consideration. For the Shuttle to achieve sufficient number of flights to obtain its cost targets, the four Shuttles would have to launch all national security satellites.[10] This meant that existing national security satellites had to undergo major reconfigurations and design changes in order to fit in the Shuttle cargo bays. It also meant

that an upper stage had to be developed to provide propulsion to transfer the military satellites from the Shuttle's orbital altitude to the satellites' mission altitudes. Moreover, all national security satellites under development would be designed for Shuttle launch only.

In late 1983, the national security space community under the leadership of Mr. Edward C. "Pete" Aldridge, who was dual-hatted as the Under Secretary of the Air Force and Director of the National Reconnaissance Office (NRO), expressed concern with risks inherent in the "Shuttle only" approach as it put all payloads on a single launch system.

Arguing that the country needed assured access in the event of a Shuttle problem, Secretary Aldridge was able to convince the White House and the Congress to purchase ten expendable vehicles to "complement" the Shuttle.[11] The Air Force competed the complementary ELV, and selected the Titan 34D7—later known as the Titan IV.

The wisdom of the assured access policy was soon to be apparent due to a tragic series of events in the mid-1980s. In August 1985, a Titan 34D failed for the first time in 18 years of flying from Vandenberg AFB, California. In January 1986, the Space Shuttle Challenger tragically exploded during its boost phase. Then another Titan 34D ELV failed in April 1986. With neither the Shuttle nor Titan operational, the United States was unable to launch the preponderance of its military or civilian spacecraft.[12] Individuals who remember these trying times are often the greatest proponents of assured access as they recall a time when we were without a launch capability.

The Nation responded to the assured access crisis through a variety of short-term and longer-term initiatives. In the short term, the Department of Defense (DoD) authorized the purchase of additional Titan IVs, the Air Force ordered the procurement of a medium launch vehicle (selecting the Delta II in January 1987), Titan II ICBMs were modified for space launch, and an advanced version of the Atlas Centaur upper stage was started.[13] However, despite these extraordinary efforts, the country's launch capability experienced a downtime of 32 months.

The longer-term initiatives resulted from the nature of US space launch vehicles available in the post-Challenger era. These boosters were costly to build and operate, were based upon 1960s era, ballistic missile-derived technology, and required a large force of technicians and months of launch preparation. Moreover, the DoD now expected that spacelift requirements would increase given the projected heavy-lift needs of the Strategic Defense Initiative's (SDI) proposed space-based missile defense systems.[14] This combination of cost, work force, responsiveness, and increased projected demand convinced the DoD to study new launch approaches.

These concerns with the current launch vehicle fleet plus an anticipation of greater launch demand and improved performance resulted in a series of efforts to modernize space launch. The first was the Advanced Launch System (ALS), begun in 1987, and conceived as a modular family of boosters capable of lifting from 5,200 lbs. up to 198,000 lbs. into low Earth orbit (LEO). However, two years later the Berlin Wall fell which signaled the end of the Cold War. Accordingly, ALS was scaled back to a technology development program. Even if ALS in its original form was not needed, the DoD still desired to improve and standardize the ELV fleet. The DoD funded another round of studies this time under a new name the "National Launch System" (NLS). NLS looked at a family of boosters and upper stages, all using a new space transportation main engine. NLS was also relatively short-lived. Congress was highly skeptical of the wisdom of the $12 billion investment, and the DoD ended the effort in 1991. The National Space Council under Vice President Dan Quayle then chartered a study called Future of the US Space Launch Capability (a.k.a. the Aldridge Study) to take a national perspective. In its November 1992 report, the study recommended developing a new medium-lift (20,000 lbs. to LEO) ELV called Spacelifter, which would form the core of a modular vehicle family able to put up to 50,000 lbs. in to LEO.[15] This idea, too, died for lack of support and funding.

The failure to proceed with ALS, NLS, and Spacelifter resulted from the inability to reach consensus on launch requirements among the key players – DoD, NASA, and the intelligence community. Nevertheless, the DoD still wanted an alternative to continuing with a very diverse fleet of vehicles having widely differing support requirements.

1994 Space Launch Modernization Plan

By late 1993, the country had several years of launch studies and false starts with no real progress toward modernization. Congress now stepped in with the 1994 National Defense Authorization Act, directing the Secretary of Defense to develop and submit to Congress, a plan that "establishes and clearly defines priorities, goals, and milestones regarding modernization of space launch capabilities for the DoD or, if appropriate, for the government as a whole."[16]

In December 1993, the Deputy Secretary of Defense formed a study group to address the congressional tasking, and asked that I lead the effort. At the time, I was the Vice Commander of Air Force Space Command. The 1994 Space Launch Modernization Plan report was the result of three months of intensive effort by a study team that included representatives of various national security and civil space organizations, including the DoD, NRO, NASA, and the Federal Aviation Administration's (FAA's) Office of Commercial Space Transportation.

One of the first things the study group examined was the "differing views and interests in this area" and the underlying causes that had led to "an inability to maintain consensus within the executive branch."[17] These differing interests and perspectives are summarized below:

- The defense space sector was most interested in cost-effective, medium-class launches for its force enhancement payloads, while seeing future needs for improved operability, dependability, and responsiveness.
- The intelligence space sector's top concern was a reliable heavy lift capability for its large and expensive payloads.
- The civil space sector focused on safe, reliable human spaceflight to assemble the Space Station and on the need to reduce the costs of space transportation by pursuing a

reusable space launch system.
- The commercial space sector was synergistic with the defense space sector because both were interested in lower prices and dependable launch schedules, and both saw limited opportunities to expand the launch market.[18]

Based on each sector's views, the 1994 study team developed five top-level requirements for future launch systems:

- Production and launch rate stability, to reduce costs, maintain continuity, and improve reliability.
- Reliability, to control the cost of failure and make resources available for investment.
- Technology, to provide a foundation for modernization at reasonable cost, schedule, and risk.
- Space launch management, to achieve consensus and reverse technological/industrial drift and atrophy.
- Funding commitment, to move beyond the austere upgrades. [19]

The 1994 SLMP addressed each of these requirements in its 15 findings and recommendations, which were divided into four groups: (1) fundamental drivers of the space launch industry; (2) critical drivers of cost, capability, or operations; (3) special focus areas; and (4) current operations enhancement areas.[20] It is not important to address the details of the study. However, from my perspective, the SLMP was successful because it considered the varied needs and attempted to create a win-win for the DoD, NRO, FAA, and NASA. With the big players on the same sheet of music, a new initiative could go forward.

The results of the SLMP formed the foundation of the 1994 National Space Transportation Policy. This policy established the DoD as "the lead agency for improvement and evolution of the current US ELV fleet, including appropriate technology development … [while] NASA will be the lead agency for technology development and demonstration for next generation reusable space transportation systems, such as the single-stage-to-orbit concept."[21]

Expendable Launch Vehicle Environment

In the EELV Cost Concept Validation phase, DoD awarded four Concept Validation contracts in August 1995. In November 1997, with a booming commercial satellite market believed to lie ahead, DoD decided to award two pre-engineering and manufacturing development (EMD) contracts rather than the expected one, and bring both vehicles onto the market. Lockheed Martin and McDonnell Douglas (which later merged with Boeing) were awarded EMD contracts.[22]

The Air Force spent $2 billion in EELV development funds, with the two companies putting in significant funds of their own. Within each company's family of boosters, the use of common components, processes, and infrastructure was expected to reduce significantly the fleet's life-cycle cost. The Air Force expected the EELV would cut the cost of launching government payloads in the National Mission Model by 25 to 50 percent (compared to Delta, Atlas, and Titan), a cost savings of $5 billion to $10 billion between 2002 and 2020.[23] It was anticipated that with the expected flood of commercial communication satellite business, the industry could sustain two robust US competitors, which would provide sufficient competition to keep the prices low.

In October 1998, during the "EELV Buy I" phase, Boeing received a contract for 19 EELV missions, while a contract for nine missions went to Lockheed Martin. Each company received $500 million in EELV EMD work. Subsequent environmental changes included the infusion of additional development funds to offset the lagging commercial market, the removal of seven launches from Boeing on the grounds of corporate misconduct, and the renewed debate on whether two EELV providers should be sustained.[24]

In 1999, the DoD faced another assured access crisis. Within a span of 10 months, five launch vehicles failed with three of these due to upper stage anomalies. In the previous two years, nine out of 51 vehicles suffered critical failures. As a consequence, a Broad Area Review (BAR) was directed by the White House that was chaired by former Air Force Chief of Staff, General Larry D. Welch. The BAR panel noted that contractors had been focusing too many resources on EELV development, and insufficient resources on the vehicles presently in service. The Review stressed mission success and recommended disciplined system engineering and the importance of a comprehensive independent review process. The BAR also noted an urgent need to identify clear lines of authority and accountability with government and industry for delivering spacecraft on-orbit.[25] In hindsight, the BAR was one of the most useful study efforts ever as the US has not experienced a launch failure since the BAR recommendations were implemented.

2004 Assured Access to Space Study

During 2003 and early 2004, there was considerable debate on the viability of maintaining both EELV providers. The launch demand, which had been projected based largely on an anticipated explosion in the commercial communications satellite market, had not materialized, and consequently, the industry was overcapitalized. Moreover, there were serious questions whether either of the EELV providers could operate profitably.

Consequently, two different views developed during the budget debates of early 2004. On one side were those in the budget oversight business—the Office of the Secretary of Defense, Office of Management and Budget, and certain Congressional committees—who favored downselecting to one EELV provider. On the other side was the operational community—the Air Force and the NRO, who were mindful of the launch problems in the mid-1980s, and wanted more assured access, that is, the insurance of two providers.

As a consequence, I was asked in the early summer of 2004 by the Under Secretary of Defense for Acquisition, Technology and Logistics in cooperation with the Under Secretary of the Air Force—the DoD Executive Agent for Space to address the following question—"What is the plan and the investments the DoD should make to better support assured access to space?"[26]

The purpose of the study was to outline the milestones, options, and alternatives to improve further the national security launch posture. The Study's output focused on providing a comprehensive analysis to support decision-making, understanding

the impact of EELV decisions on future launch options, and identifying events or actions that could reduce uncertainty.

The study was conducted as a contractor-led, government-supported activity throughout the summer and fall of 2004. Advising and guiding the execution of the study were some of the Nation's foremost experts on space launch from government and industry. It should be noted that the study was neither a total update of the 1994 SLMP plan nor a new plan, but a focused update on assured space access and reliability as those factors apply to the EELV program and options. The study team set out to determine:

- The relationship between launch and production rates and reliability.
- Whether a single EELV provider could provide the reliability, performance, and necessary infrastructure to meet national space requirements.
- What benefits and cautions apply to the four options: maintaining two EELV providers; down-selecting to a single EELV provider; establishing a joint hybrid model; and developing a new launch system.
- Investment options that could better support assured space access.[27]

The study approach included extensive data gathering from a wide variety of government stakeholder organizations and industry representatives. Over the course of four months, the study team interviewed and visited a broad range of government and industry stakeholders, including the programs offices, major launch providers, sub-tier suppliers, and small launch vendors.

The following sections provide an overview of the study's methodology and primary lines of inquiry.

Demand

The study team's analysis of the demand function found that the total current addressable EELV market was about half that of the 1994 SLMP projection, and approximately 40 percent of the 1998 projections made by the Department of Transportation's Commercial Space Transportation Advisory Committee. In addition, the analysis showed that the DoD was the largest user in the EELV market, comprising more than 80 percent of the total launch demand and that this percentage would continue for the foreseeable future.[28] Reduced expectations for EELV commercial capture and NASA's consistent use of Delta II resulted in a 2004 prediction of only 12 missions a year (figure 1). Specifically, the current EELV demand projection (averaged across nine years) shows about 10 DoD missions per year, 1.4 NASA missions per year, and one commercial mission per year.[29]

An additional factor in demand modeling is the impact of schedule slips. The actual number of flight rates is usually less than the original projections. This phenomenon is sometimes referred to as the "Gooch Factor" after Col Larry Gooch, USAF, retired who had commanded both East and West Coast launch organizations. He observed that the Nation only launches approximately 70 percent what it plans to launch. The study team audited this claim by comparing the mission model from the 1994 SLMP to the actual number of flights that have flown since then. As Colonel Gooch had predicted, the analysis showed that 70 percent of the planned launches from 1995-2004 were actually flown (figure 2). The study team applied the 70 percent "Gooch factor," and arrived at a revised forecast of 75-110 total launches for the period of 2005–2013 (figure 3).[30]

The bottom line for EELV demand is that it is significantly different in both magnitude and composition than in prior years. The DoD dominates the mission model, which consists of eight to 12 missions a year, and only includes limited NASA and commercial missions.

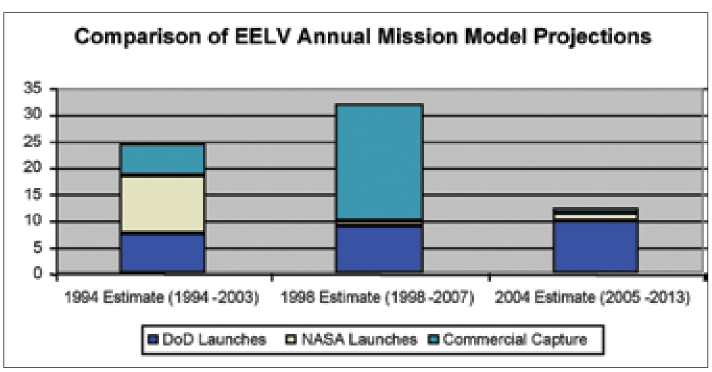


Figure 1. Comparison of EELV Annual Mission Model Projections.

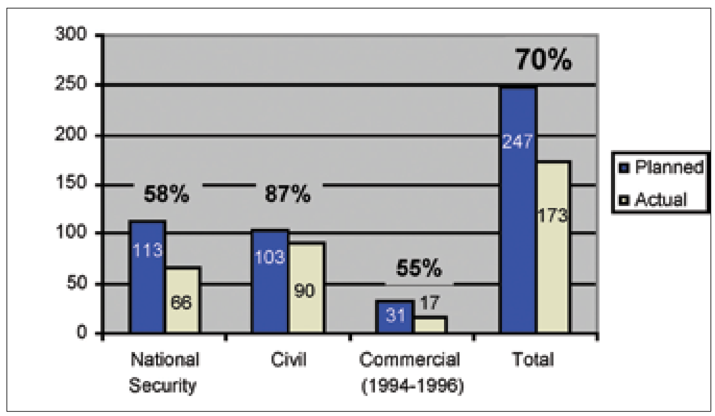


Figure 2. Planned versus Actual Launches, 1995-2004.

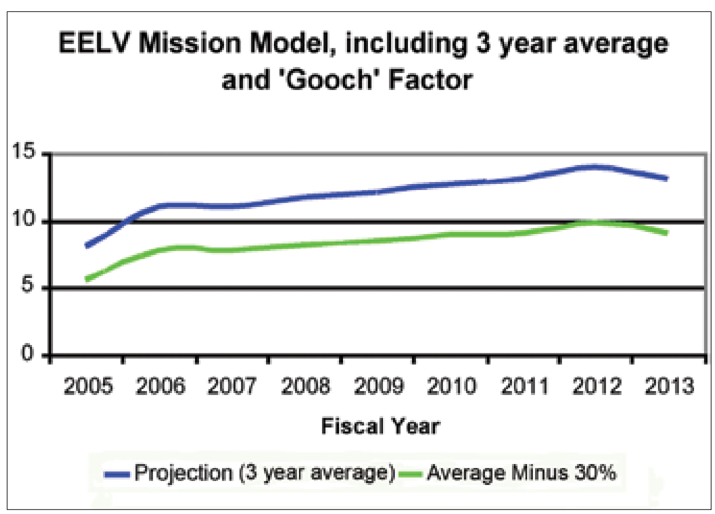


Figure 3. Range of Forecasted Launches, 2005-2013.

Reliability

The study team found that design and process reliability are the key factors influencing mission and launch reliability. Early in a program, demonstrated reliability is not a significantly relevant metric due to the extremely high number of launches required to establish an acceptable confidence interval.

The study team found value in an approach, which measures early launch system reliability and predicts life cycle reliability, pioneered by Mr. Edmardo "Joe" Tomei and Dr. Sergio Guarro of the Aerospace Corporation. The Aerospace analysis indicated that the first three launches of a vehicle type drive out 85-90 percent of design reliability issues, while the first seven launches uncover most process reliability issues. After the first seven launches of a new program, failures are not correlated with flight number and are almost exclusively caused by process and workmanship errors.[31]

Process reliability is a function of both production and operations parameters. Contractors design their processes for a specific range of units. If production or operations exceed the process limits, then error will result because of rushed labor. Alternatively, if production or operations fall below the minimum process limit, workers struggle to maintain their proficiency (figure 4).

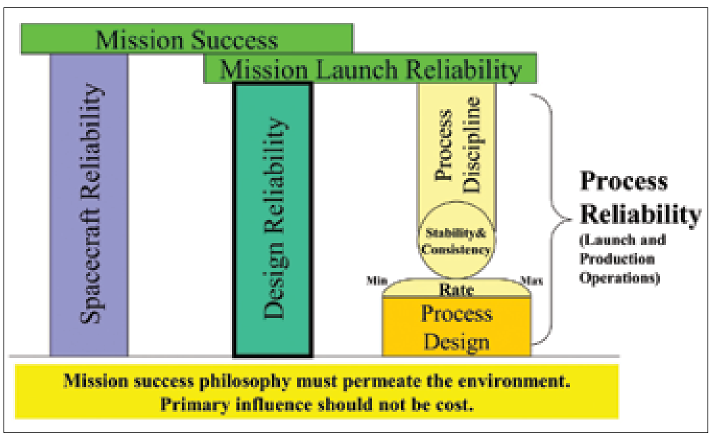


Figure 4. Reliability and Mission Success.

The study team applied the 3/7 launch reliability methodology to each EELV model. Within an EELV family, variations exist between models; however, the common components within an EELV family should not be ignored. For example, design reliability of the four-meter payload fairing of the Delta IV family is considered mostly retired after three launches of a Delta 400-series booster. Similarly, process reliability of the Atlas V solid rocket motors is established after seven launches of Atlas vehicles with strap-on motors. The conclusions from 3/7 reliability analysis were incorporated into the team's assessment of uncertainty (discussed later).

Resiliency

The study found that most people wanted to describe assured access in terms of reliability. As the study team progressed in our analysis, it became apparent that often what people were describing was the need for resiliency rather than reliability. Reliability describes the dependability of a specific booster while resiliency considers the collective ability of all available launch systems to meet national security needs. Given the potential confusion between resiliency and reliability, the study team believed that it was important to establish a common understanding of resiliency.

One commonly raised scenario in a down-select situation is the potential for the selected launch provider to have a failure, with no available back-up launch capability. In this case, a critical payload could not fly, constellation health would be impacted, and on-orbit capability would be diminished. In a downselect scenario, the extent of the consequences related to resiliency is scenario-dependent.

With only one EELV provider, there are significant consequences in a "maximum regret scenario," defined as a significant capability shortfall resulting from a single launch failure. Under this scenario, an on-pad failure of an unrelated payload occurs before the scheduled replacement can be launched. If the DoD had not invested in additional launch facilities on each coast, the launch stand-down time following the failure could be as long as 23 months. However, if additional launch pads were built on each coast, the launch slip could be only six months.[32] Accordingly, the study team concluded that investment in additional launch pads on each coast (under a one-provider scenario) greatly speeds recovery after a launch failure. The greatest value of resiliency is tied to this maximum mission regret scenario.

There are also a series of financial cautions under a down-select scenario. The government would likely need to invest more in the remaining provider to reduce risk. For example, a down-select to a single provider may require building additional launch pads on each coast, and possibly other infrastructure as well.

Down-selecting to one provider can also increase risk by having "all eggs in one basket." If there are two EELV providers and one vehicle family experiences an off-pad failure, the payloads on the unaffected provider can still fly on schedule. In

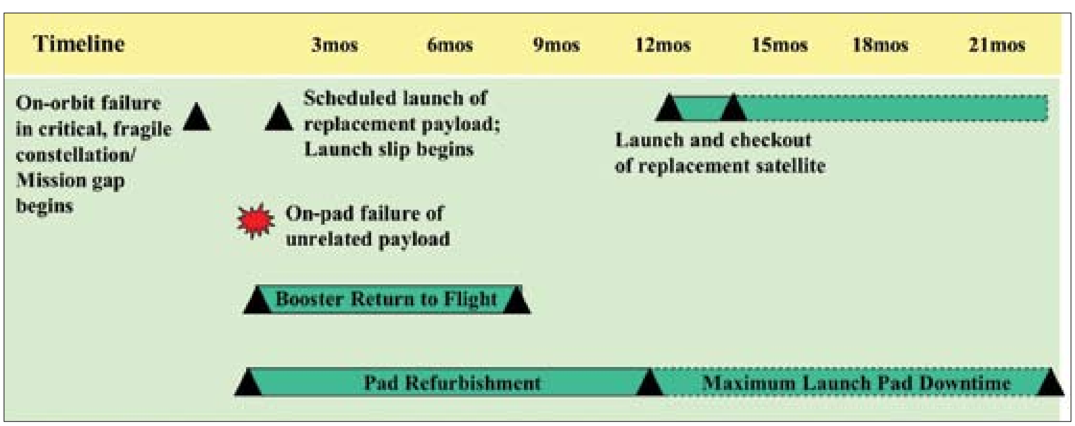


Figure 5. Maximum Regret Scenario – Single Provider.

a down-select scenario, without non-EELV backup launch capability, every payload rides on one vehicle family; hence, if there is a problem with that vehicle family, every payload is affected.

EELV Options

The outputs of this study included options with key investment milestones. It is important to emphasize that the study did not recommend one EELV option over the others. Instead, the study output was a comprehensive analysis to support decision making on the way ahead—to understand the impact of EELV decisions on future launch options and to identify events or actions that can reduce uncertainty. This latter statement is all-important as all options have varying degrees of uncertainty. The study team highlighted the tremendous interplay and interaction of benefits and cautions across the four options:

- **Down-select to one EELV provider,** at a specified time or in response to certain criteria. Benefits of this option included cost savings, improved business case, and higher production and operations rates. Some of the relevant cautions were increased uncertainty, the difficulties inherent in ensuring a level playing field in the down-select competition, reduced future launch options, and limited resiliency.
- **Maintain two EELV providers** for the near future with no plan to down-select. Benefits included hedging uncertainty, preserving options for the future, and ensuring resiliency. Cautions included higher infrastructure costs, sustainment of out-year funding, and process reliability risks with low launch and production tempo.
- **Combine EELV operations.** This option involved the two contractors combining their engineering, production and launch capabilities into a joint venture. This option would dampen both the upside and downside of the benefits and cautions associated with previous options. The primary caution is industry's willingness to embrace this approach.
- **Develop a new launch system.** A new launch system could be based on the most modern technology and could integrate NASA's evolving needs. Of course, the downside or caution of a new launch system is the massive investment and lengthy development and test time.[33]

Uncertainty

Understanding and quantifying uncertainty is key to informed decision making. In that light, the study team drew three general conclusions regarding uncertainty:

- Each option contains uncertainty, and the difficulty in choosing an option is directly related to uncertainty.
- Uncertainty changes over time and is reduced as events occur.
- Events can be identified or created such that their successful execution may reduce uncertainty.[34]

With respect to the specific issue at hand, the study team examined existing space launch policy and strategies, acquisition plans and programs, and development and operational plans. The team identified five major factors that affect uncertainty:

- **Proven EELV.** At the time of this study (October 2004), the EELV program had completed six successful flights. The low number of total EELV flights systems at that time represented a high degree of uncertainty in system-life reliability.
- **Business Case.** This category of uncertainty included the timing, scope, and acquisition strategy of future EELV buys; the financial pressures resulting from the meager commercial demand; and the effects and duration of the Boeing suspension.
- **Engines.** Despite the demonstrated success of current rocket engines, there are uncertainties in engine flight time and test data, the timing associated with US production capabilities, and the future viability of EELV engines.
- **Heavy Launch Capability.** It will require several years to establish some degree of confidence in EELV heavy lift capability. As of this writing, the US has only launched one heavy EELV (August 2006).
- **NASA Requirements.** NASA had not identified its future requirements for heavy lift by the conclusion of this study. Since then, NASA has decided not to use EELV to meet any of its space exploration mission needs.[35]

The study team conducted a detailed analysis of these factors over time in order to understand their impact on the decision making environment. To that end, the team identified events, activities, and milestones that could reduce uncertainty.

Based on this analysis, the study team made three important observations. First, there were no simple or unambiguous decisions regarding the way ahead for EELV as each option possesses significant uncertainty. Second, there are actions that can make the EELV options more attractive, or reduce the uncertainty. Finally, there are identifiable time periods in which uncertainty will be collectively reduced.

In summary, the 2004 Assured Access to Space Study determined that this is an enormously complex issue with no easy solutions. What was clear is that the demand for EELV was and still is significantly less than that envisioned in 1994. The Nation appears to have two very capable, but relatively immature systems. The interplay between the benefits and cautions underscores the complexity and uncertainty facing decision makers. Uncertainty remains high although reductions in uncertainty are projected at the end of 2007 and in 2009.[36] Given this degree of uncertainty and the associated risks, the DoD chose to continue to fund two EELV providers.

In May 2005, Boeing and Lockheed Martin agreed to form a joint venture (the third option examined in the study) that would combine the production, engineering, test and launch

As a nation, we need to continue to adequately fund space launch operations and develop the next-generation technologies that will increase responsiveness, improve reliability, and reduce costs.

operations associated with US Government EELV launches. The DoD and the Federal Trade Commission approved this joint venture in October 2006.

Summary and Conclusions

The Air Force has come a long way in its 60 years of space launch. Today, our space launch systems are achieving extraordinary reliability, demonstrated by a current streak of 47 consecutive launch successes across a variety of systems. This unprecedented success is due to a solid technology base, a strong government and industry partnership that emphasizes mission success and sustained, committed leadership by the Air Force.

While our recent launch record which includes 13 of 13 EELV successes is indeed impressive, we should not rest on our laurels. Assured access is not a destination, but rather a journey. As a nation, we need to continue to adequately fund space launch operations and develop the next-generation technologies that will increase responsiveness, improve reliability, and reduce costs. Through these actions, we can ensure the Nation will have continuous, uninterrupted access to space for decades to come.

Notes:

[1] "US Space Transportation Policy," fact sheet, 6 January 2005, http://corport.hq.nasa.gov/launch_services/Space_Transportation_Policy.pdf#search=%22SpaceTransFactSheetJan2005%22 (accessed 25 September 2006).

[2] Curtis Peebles, "High Frontier: The United States Air Force and the Military Space Program," Air Force History and Museums Program, 1977, 8.

[3] David N. Spires, *Beyond Horizons: A Half Century of Air Force Space Leadership* (Air Force Space Command, 1998), 51.

[4] Curtis Peebles, High Frontier, 10.

[5] David N. Spires, *Beyond Horizons*, 77.

[6] Enabling Assured Access to Space Study: Launch Vehicle Appendix (McLean, Booz Allen Hamilton, 2004), 8.

[7] Ibid, 19.

[8] Ibid.

[9] Ibid, 20.

[10] E.C. Aldridge Jr., "Assured Access: The Bureaucratic Space War," Dr. Robert H. Goddard Historical Essay, 1.

[11] Curtis Peebles, High Frontier, 28.

[12] E.C. Aldridge Jr., Assured Access, 14.

[13] Ibid, 15.

[14] Enabling Assured Access to Space Study, appendix, 51.

[15] Ibid, 51-52.

[16] Enabling Assured Access Final Report, (McLean, Booz Allen Hamilton, 2005) 9.

[17] Ibid.

[18] Ibid.

[19] Ibid.

[20] Ibid, 11.

[21] National Space Transportation Policy, 5 August 1994, http://www.au.af.mil/au/awc/awcgate/nstc4.htm (accessed 26 September 2006).

[22] Enabling Assured Access Appendix, 55.

[23] Ibid.

[24] Ibid.

[25] Space Launch Vehicles Broad Area Review Panel, Space Launch Vehicles Broad Area Review briefing, November 1999, http://klabs.org/richcontent/Reports/Failure_Reports/Space_Launch_Vehicles_Broad_Area_Review.pdf#search=%22broad%20area%20review%22 (accessed 26 September 2006).

[26] Enabling Assured Access Final Report, 3.

[27] Enabling Assured Access Final Report, 4.

[28] Ibid, 4.

[29] Ibid, 16.

[30] Ibid.

[31] Joe Tomei and Sergio Guarro, "Building Confidence in EELV" (Aerospace Corporation, 2004).

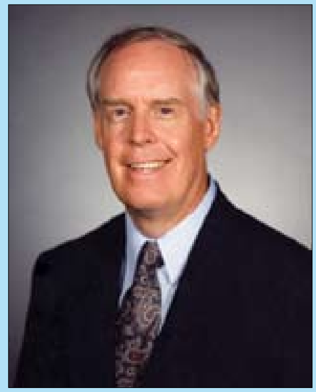
[32] Enabling Assured Access Final Report, 29.

[33] Ibid, 6.

[34] Ibid, 41.

[35] Ibid, 42.

[36] Ibid, 49.



General Thomas S. Moorman, Jr., USAF, retired (BA, History and Political Science, Dartmouth College; MBA, Business Administration, Western New England College; MS, Political Science, Auburn University) is currently a Vice President at Booz Allen Hamilton responsible for the firm's Air Force and NASA business. General Moorman retired as the Vice Chief of Staff of the United States Air Force.

As a member of the Congressionally-directed Space Commission, he played a key role in formulating its findings and recommendations. He led Booz Allen's USD Acquisition and Technology and Director NRO-sponsored study of the US Space Industrial Base. Subsequently, he led a number of space industrial base-related efforts for the government.

In General Moorman's last military assignment as Vice Chief of Staff, United States Air Force, he acted on behalf of the Chief of Staff during his temporary absence. He oversaw and managed the day-to-day activities of the Air Staff at the Pentagon, chaired the Air Force Council, and was the Air Force representative to a number of joint and interagency organizations including the Joint Resources Oversight Committee, the Defense Medical Advisory Committee, the Senior Readiness Oversight Committee, and the Quadrennial Defense Review. General Moorman also chaired the Air Force Board of Directors charged with developing the Air Force strategic vision for the 21st century.

As Commander and Vice Commander of Air Force Space Command from 1990 to 1994, General Moorman was responsible for operating military space systems; ground-based radar and missile warning satellites; the Nation's space launch centers at Patrick AFB, Florida, and Vandenberg AFB, California; the worldwide network of space surveillance radars; and maintaining the intercontinental ballistic missile (ICBM) force. As Commander, General Moorman provided Air Force space support to the coalition forces during Operations Desert Shield and Desert Storm.

In addition to numerous military awards and decorations, General Moorman was honored several times for contributions to the Nation's and the Air Force's space programs. Representative commendations include the Dr. Robert H. Goddard Memorial Trophy (1995), the premier award of the National Space Club; the National Geographic Society's General Thomas D. White US Air Force Space Trophy (1991), awarded for outstanding contributions to the Nation's progress in space; the American Astronautical Society's Military Astronautics Award (1997); the Ira C. Eaker Fellowship Award (1994), to honor significant contribution in Air Force space systems and the Tennessee Ernie Ford Distinguished Achievement Award (1996), for exceptional leadership in US space programs. In 1998, General Moorman was chosen by the American Institute of Aeronautics and Astronautics as the Von Karman lecturer, and the National Air and Space Museum to present the Wernher von Braun lecture.

The Air Force and the Federal Aviation Administration: Partners for Space Access

Ms. Patricia Grace Smith
Associate Administrator, Office of Commercial Space Transportation, Federal Aviation Administration

In April 2006, the Air Force and the Federal Aviation Administration (FAA) convened a summit meeting in Colorado Springs, Colorado. The event made it possible for private entrepreneurial launch vehicle developers to come together and show how their work might help meet Air Force needs on the high frontier of space. After the developers finished their presentations, Air Force representatives spoke about a number of their space activities and possible areas where the initiative of private enterprise might play a role.

On the surface, it appeared to be a fairly conventional gathering. But what distinguished this meeting from previous ones was that … there had *never been* any previous ones. This was a milestone, the first time the new wave of private launch vehicle entrepreneurs had ever met as a group with the Air Force.

What took place in Colorado Springs underscored the fact that a new and growing number of private providers are working on a variety of ways to deliver ready access to space. And it further emphasized the value of the strong and effective partnership that the meeting sponsors—the Air Force and the FAA—have been building for years. It showed how two organizations working closely together could help build better connections to possible vendors. That's something of value, certainly to the vendors, and potentially to the Air Force and the Nation. Of course, the FAA was glad to take a lead role in arranging the summit since promoting and facilitating the commercial space industry is a part of the dual mission at the FAA's Office of Commercial Space Transportation.

That said, people unfamiliar with it might still ask what an Air Force and FAA partnership has to do with access to space anyway, or for that matter, with space flight of any kind. While it is not hard to appreciate the Air Force side of the relationship, it is equally important to understand the reason for the FAA's involvement.

The Federal Aviation Administration in Space – the Office of Commercial Space Transportation

By Executive Order in 1984, President Ronald Reagan established the Office of Commercial Space Transportation in the Department of Transportation (DOT). In October of 1995, the office became a line of business within DOT's FAA and led by the Associate Administrator for Commercial Space Transportation (AST). Simply put, AST regulates commercial space transportation, the only office in the US government that does so, and promotes the development of the US commercial space transportation industry.

AST duties include licensing commercial space launch operations to determine whether a planned launch can be done safely, without injury to the uninvolved public or damage to property. The office also licenses the operation of re-entry vehicles and issues experimental permits for suborbital reusable launch vehicles (RLVs). Finally, AST licenses the operation of non-federal launch sites, more commonly called spaceports, currently totaling six including commercial operations at Vandenberg AFB, California; the Mojave Civilian Flight Test Center, California; the Virginia Space Flight Center at Wallops Island, Virginia; the Florida spaceport at Cape Canaveral, Florida; the Kodiak Launch Complex in Alaska; and the Clinton Sherman Industrial Airpark near Burns Flat, Oklahoma.

AST launch operation activity was exclusively focused on expendable launch vehicles (ELV) until 2004. That year, AST licensed the launch and re-entry of SpaceShipOne, an RLV, that went on to capture the $10 million Ansari X-Prize. As a result of the Commercial Space Launch Amendments Act of 2004, AST was assigned du-

April 2006 Entrepreneurial RLV Developer Summit, Colorado Springs, Colorado. Government space leaders hear RLV Industry presentations. Shown left to right, Lt Gen Frank G. Klotz, Vice Commander AFSPC; Dr. Ronald M. Sega, Undersecretary of the Air Force; Ms. Patricia Grace Smith, Associate Administrator for Commercial Space Transportation, FAA.

ties for commercial human space flight and is now in the rule making process governing the crew and passengers for commercial suborbital RLVs and for experimental launch permits. After more than two decades of licensing experience with ELVs, the Office of Commercial Space Transportation is preparing for its expanded role in commercial human space flight.

The Air Force and the Federal Aviation Administration Partnership – Common Launch Safety Standards

The Air Force and the FAA partnership reaches back nearly a decade to 1997 when the two organizations began work on developing common launch safety standards. In February 2000, an interagency working group led by the White House Office of Science and Technology and the National Security Council recommended that the Air Force and the FAA "continue their cooperative development of common safety requirements to be applied to government and commercial launches at federal and non-federal launch sites."

In the years that followed, the Air Force devoted considerable resources and time to this intensely thorough effort, eventually involving more than 100 technical experts and engineers assigned to the Common Standards Working Group. All the effort was aimed at further ensuring safety, while reducing administrative burdens for users at ranges where both the FAA and the Air Force have responsibilities to maintain public safety.

As the range of commercial space expands, and Air Force missions evolve, the value of the Air Force and Federal Aviation Administration partnership and the connection with the private entrepreneurial space sector can pay even greater economic and national defense dividends in the years to come.

The work was part of an evolutionary process. For years, the Air Force has protected the safety of the uninvolved public at federal ranges. The FAA's responsibility to maintain public safety during *commercial* launches amplified the need for Air Force and FAA cooperation at federal ranges. Rapidly emerging interest in non-federal launch sites called out for the same approach to public safety that exists at federal sites.

The commitment of the partners, in concert with the industry, has succeeded. On 25 August 2006 the FAA formally issued new common launch safety standards designed to create consistent, integrated space launch rules and requirements for the Nation. This new rule will strengthen public safety by harmonizing launch procedures that help identify potential problems early and by implementing a formal system of safety checks and balances. The new regulations govern commercial ELV launch operations at federal and non-federal launch sites. By codifying safety practices derived from decades of Department of Defense and NASA experience and now in place at federal ranges, proven safety requirements are now readily accessible in one document.

Common launch safety requirements for all launch sites means that launch providers can more easily use systems qualified at other ranges. Common requirements are a boost to federal programs launching at multiple ranges such as the Missile Defense Agency that uses both federal and non-federal launch sites. Moreover, the Air Force and the FAA partnership has already facilitated the launch mishap investigation process by promoting better planning, coordination, and information sharing.

As the partnership has grown, it has generated benefits along the way and produced formal, common standards, of value to launch operators, the FAA and the Air Force and, most important, the public. Beyond these vital benchmarks, by bringing the parties closer, it means access to space will improve, not only by insuring common rules, but also by creating an environment more hospitable to more launch operators.

A Partnership Open to the Future

At the April entrepreneurial space summit, Lt Gen Frank G. Klotz, Vice Commander of Air Force Space Command, noted the number one job in his command is supporting the warfighter. In that regard, he said there were a number of things in which the Air Force was interested, including "the area of responsive spacelift … the area of responsive spacecraft." That is an opportunity environment where the commercial world can deliver a service.

That same month, in an article for this journal, he wrote: "Space is an inherently joint activity."[1] Those six words are at the heart of the Air Force and the FAA partnership and unquestionably at the heart of America's need for assured access to space.

The Air Force has led the way to assured space access and has begun to look closely at RLVs as evidenced by its work on the Affordable Responsive Spacelift program. The Air Force Research Lab (AFRL) at Wright-Patterson AFB, Ohio has the lead on the program, and AFRL is an advocate for strengthening the RLV community through partnerships with the FAA and commercial launch providers. The principal goal is to build reusable systems more quickly with cutting edge technical advances to ensure that the Air Force can meet its assured access to space goals.

The key beneficiaries of this work are the combatant commanders. They use the global positioning satellites for navigation and targeting and weather satellites for air tasking order development and movements. They use space-based communications capabilities for blue force tracking and real- time targeting. These commanders constantly request more bandwidth and more advanced systems to complete their missions. These resourceful commanders will still send up an aircraft when necessary as a communications relay, but they recognize that space systems provide the optimum stable, reliable, and secure communications option.

Without question, the years ahead will intensify demand for a variety of launch assets to give warfighters the agility and the redundancy to deliver uninterrupted, high-quality command and control access to theatre operations. In pursuit of that objective, new ways will have to be found to shorten flight plan approval, assure global coverage, increase capacity, and shrink the time between target identification and delivery of appropriate resources, linked to space-based assets.

In that respect, NASA announced the winners of the Commercial Orbital Transportation Services competition in late August. The companies chosen will develop vehicles intended to service the International Space Station. The testing and flights of those vehicles, which will be licensed by the FAA, will involve manned and unmanned orbital flights and could produce outcomes of substantial interest to the Air Force.

The Commercial Component of Assured Access

There is nothing revolutionary about commercial involvement in warfighter skies. Reaching back to World War II it was Bell, Boeing, Chance Vaught, Consolidated, Curtiss, Grumman, Lockheed, Martin, North American, Northrop, and others that built the planes that made the skies our own.

In the same tradition of technical know-how and innovation, another generation of vehicle builders is preparing for involvement in a world of affordable access to space, with the potential to help in everyday support of national defense needs and essential support of the warfighter as circumstances may warrant.

When General Klotz said "space is an inherently joint activity," he was speaking from the lessons of our history and looking to tomorrow and beyond. The commercial space transportation industry has established itself as a dynamic, exciting industry, responsible in 2004 for more than $98 billion in economic activity, $25 billion in earnings, and more than 550,000 jobs. It is an industry with a lineage of experience and reliability expanding into an additional line of business … private human space flight.

The commercial sector brings with it the potential for a diverse range of vehicles and launch options that can help avoid total reliance on any one vehicle, or any single launch site. That would give the Nation an extended set of dependable space transportation alternatives, a vital factor in any program of assured access to space. As the range of commercial space expands, and Air Force missions evolve, the value of the Air Force and the FAA partnership and the connection with the private entrepreneurial space sector can pay even greater economic and national defense dividends in the years to come. The potential for delivering new results as well as new opportunities holds great promise.

Today, around the world, nations are embracing the promise of space and developing hardware and programs of their own. They are enthusiastic about the commercial payload side, and the exploration side. And they are not unaware of the national security implications. In the United States, we have an extra advantage. To the enthusiasm and innovation of our own new space entrepreneurs, we can add nearly five decades of experience in national defense, civil, and commercial space. It is a powerful combination of assets—an unfolding partnership—pointing the way to assured space access, while reinforcing our leadership role on the high frontier.

Notes:

[1] Lt Gen Frank G. Klotz, "Space Command and Control: The Lynchpin to Our Success," *High Frontier* 2, no. 3 (April 2006): 2.

Ms. Patricia G. Smith (BA, Tuskegee University) serves as Associate Administrator for Commercial Space Transportation within the Department of Transportation's Federal Aviation Administration (FAA), heading the office responsible for overseeing and regulating the US commercial space transportation industry.

Ms. Smith's work has contributed significantly to help FAA keep pace with the rapid changes affecting the industry. She has worked extensively to develop new and updated licensing, experimental permits, and insurance regulations for commercial launch operations, as well as working to ensure that the industry remains a leader in a growing, internationally competitive marketplace.

Ms. Smith began her career at the Department of Transportation (DOT), Office of Commercial Space Transportation (OCST) in November 1994, as Associate Managing Director. In 1995, she became OCST's Chief of Staff. In November 1995, OCST was transferred from DOT's Office of the Secretary to the FAA as an additional FAA line of business. With this transfer, Ms. Smith was named Deputy Associate Administrator for Commercial Space Transportation (AST), joining the ranks of FAA's Senior Executive Service. In June 1998, Ms. Smith was named FAA Associate Administrator for Commercial Space Transportation.

From 1980 to 1994, Ms. Smith held important leadership positions within the Federal Communications Commission (FCC). She first served as Chief of FCC's Consumer Assistance and Small Business Office, Office of Public Affairs and later as Deputy Director for Policy, Office of the Managing Director. In addition to her principle responsibilities, Ms. Smith worked on several major initiatives on behalf of the agency, among them as executive committee team member for the FCC Spectrum Auctions Implementation Team that produced the very first and largest auction of US assets in history. Ms. Smith, along with her team members, received Vice President Gore's Hammer Award.

Ms. Smith also held positions at the Department of Defense, Defense Communications Agency, Acquisition Policy Office, and the Senate Commerce Committee.

Ms. Smith did graduate work at Auburn University, George Washington University, and Harvard University School of Business. In 1996, she was awarded the Distinguished Alumni Award from Tuskegee University. She is the recipient of numerous other awards and has served on several boards.

Launch Readiness Verification on the Evolved Expendable Launch Vehicle Program

Mr. Ray F. Johnson
Vice President Space Launch Operations
The Aerospace Corporation
Mr. Edmardo "Joe" Tomei
Space Launch Operations Chief Engineer
The Aerospace Corporation

The catastrophic failures of Space Shuttle Challenger and Titan 34D-9 within three months in 1986 had a devastating effect on the Department of Defense (DoD) space community, and resulted in a series of actions to recover from the lack of space access caused by these disasters. The Titan, Delta, and Atlas launch programs, which were in the process of being phased out, were revitalized; the Air Force Space Shuttle Program was cancelled; and a series of far reaching studies were performed over several years. All of these actions had as their primary motive assuring access to space for national security. The resulting Space Launch Modernization Plan of 1994,[1] directed by Congress and led by General Thomas S. Moorman, presented various alternatives ranging from no change at all to a complete overhaul of the space launch acquisition strategy. To meet DoD's future launch needs, the Evolved Expendable Launch Vehicle (EELV) concept was chosen as the best balance between cost and risk.

Evolution of Evolved Expendable Launch Vehicle Program

EELV sought to eliminate the variety of expendable launch vehicles—Titans II and IV, Delta II, Atlas II, and so forth—and have all DoD payloads fly on one family of EELV rockets. That meant the launch pads and payload interfaces would all need to be standardized, and the rockets would employ a modular design to accommodate different payload classes.

By 1997, the worldwide demand for commercial launches into geosynchronous transfer orbit was expected to grow dramatically. Given this robust commercial market, the Air Force decided to revise its acquisition strategy and allow two contractors to proceed into the engineering, manufacturing, and development phase and receive Initial Launch Service contracts. Giving the Air Force a choice in selecting the launch provider would assure access to space by providing options in awarding space flight missions.

This cost-sharing arrangement provided only partial funding for the development of the two launch systems. The balance would come from the contractors themselves. In exchange, the contractors would retain ownership and control of all system designs and launch operations and could thus shape their development plans to support long-term corporate goals. The government plan was to rely on the commercial market to establish confidence in vehicle reliability rather than performing traditional mission assurance. The government assumed that seven or eight commercial missions would fly on EELVs prior to the first government mission.

Shortly after the Air Force changed its acquisition strategy, the Delta III and Titan IV systems experienced significant failures between 1997 and 1999. As a result, the government formed a Broad Area Review (BAR) of Space Launch,[2] headed by former Air Force Chief of Staff General Larry D. Welch, retired, to investigate and evaluate potential systemic causes of failures across all launch systems. The BAR found that engineering process and workmanship errors were the primary cause of the launch failures and degradation of system engineering, risk management, and government were also contributors. The BAR firmly recommended that the Air Force EELV Program heed the lessons of the heritage launch failures and become a "smart, more involved customer." During the same period, the projected boom in the commercial market began to dissipate and the number of commercial missions that would occur before the first government missions were drastically reduced, effectively eliminating the risk reduction anticipated by the original Air Force acquisition plan.

As a result of the BAR recommendations, additional mission assurance steps were taken on EELV. Early in the program independent mission assurance typically performed by The Aerospace Corporation on DoD launches was not planned since government involvement was limited to an "insight" role in the commercial acquisition approach. However, as the program approached the first government launch (DSCS A3, March 2003), an increased emphasis on government mission assurance led to a reinvigoration of Aerospace's role toward a more traditional independent launch readiness verification.[3]

The EELV program includes two families of launch vehicles—the Atlas V and the Delta IV—along with their associated infrastructure and support systems, assuring independent access to space. Each is based on a two-stage, medium-lift vehicle, augmented by solid rockets as needed to increase payload capability, and a three-core, heavy-lift variant. Both have achieved notable successes in their early launches, but the EELV program is still in its infancy, and will need continued scrutiny to ensure that the anticipated gains in cost and reliability will be realized over the long term.

Atlas V Family

The Atlas V traces its roots to the Atlas intercontinental ballistic missiles developed in the late 1950s. First used as a space launch vehicle for Project SCORE in 1958, its modern evolution begins with the Atlas IIA, introduced in 1992. The Atlas IIA fea-

tured a three-meter-diameter, pressure-stabilized booster powered by three liquid oxygen/kerosene (booster and sustainer) engines. The rocket's upper stage—the Centaur II—was also three-meters in diameter and featured a dual RL10A-4 engine. The Atlas IIAS, introduced in 1993, used four solid rocket boosters to increase performance.

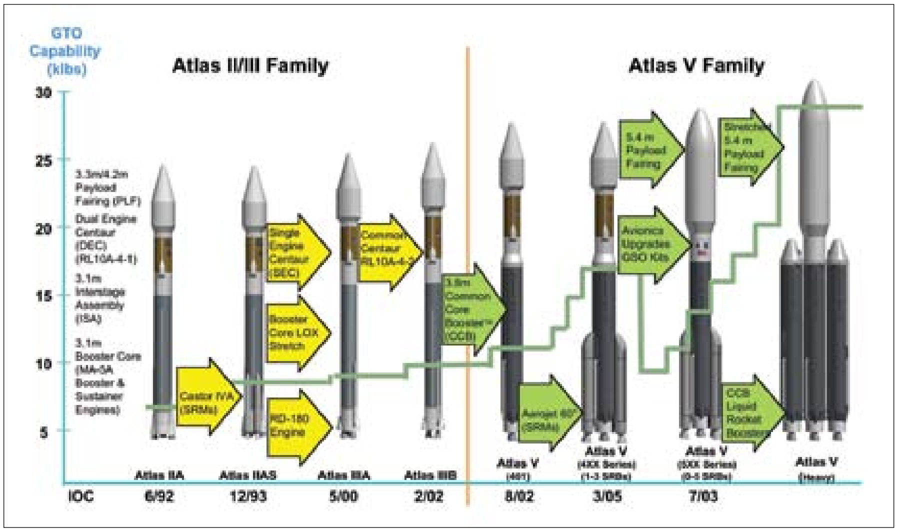


Figure 1. Atlas V Vehicle Family Evolution.

The next major Atlas variant, the IIIA, successfully flew on its first attempt in May 2000. This vehicle included the Russian-built RD-180 engine, which is also featured on the Atlas V. This arrangement provides significant challenges for the government in conducting flight verification activities due to restrictions on access to RD-180 design and test data. Pratt & Whitney Rocketdyne is in the process of developing an RD-180 US co-production capability as a risk-reduction effort. The Atlas IIIA was also the first to use the Centaur III upper stage. The Atlas evolution continued with the IIIB, first flown in February 2002. This vehicle introduced the Common Centaur upper stage, which can be flown with either single or dual RL10A-4-2 engines.

The final step in the Atlas evolution was the introduction of the 3.8-meter-diameter common core booster, which forms the basic building block of all Atlas V vehicles. Upgrades to avionics and redundant systems were also incorporated. The Atlas V core vehicles can be equipped with payload fairings measuring four- or five-meters in diameter; the four-meter version can carry up to three solid motors, and the five-meter version can carry up to five. A heavy-lift version consists of three common core boosters strapped together. All variants use the same main engine, core booster, Common Centaur, and avionics. This commonality enables the Atlas V to support a wide range of missions and facilitates upgrade from one variant to the next if performance requirements increase. The Atlas V is the first Atlas that can support direct injection into geosynchronous orbit. The four-meter vehicles can lift 4,950–7,620 kilograms to geosynchronous transfer orbit, the five-meter series can lift 3,950–8,665 kilograms, and the heavy lift vehicle can lift 12,600 kilograms.

Delta IV Family

The Delta IV lineage also traces back to the late 1950s and has its origin in the Thor ballistic missile. First used as a space launch vehicle in 1958 on the Pioneer lunar missions, the Thor evolved into the Delta launch vehicle in 1960. The modern evolution stems from the Delta II, which completed its first mission—a global positioning system (GPS) satellite launch—in 1989. Delta II configurations use the RS-27A liquid-oxygen/kerosene main engine on a core vehicle measuring 2.4-meters in diameter. The Delta II is dependent on strap-on solid rocket motors for liftoff. The second stage is powered by an engine running on N2O4 and Aerozine 50. For high-energy missions such as a GPS transfer orbit or Earth escape trajectory, a third stage can be added with a solid rocket motor.

The next development was the introduction of a four-meter-diameter cryogenic (liquid-oxygen/liquid-hydrogen) upper stage on the Delta III, powered by an RL10B-2 engine. The RL10B-2 is similar to the RL10A-4 flown on the Centaur and includes an extendable nozzle. The Delta III booster uses a shorter and wider fuel tank than the Delta II to accommodate the larger upper stage and payload fairing. In addition, slightly larger graphite-epoxy solid rocket motors were employed. The Delta III doubled the performance of the Delta II, allowing it to fly a much larger class of payloads.

The final step in the evolution of the Delta IV brought the Delta III four-meter-diameter upper stage to a new five-meter-diameter common booster core. The core's RS-68 main engine is the first liquid-oxygen/liquid-hydrogen main engine developed in the United States since the Space Shuttle Main Engine (SSME). It uses a gas-generator cycle with a relatively low chamber pressure. Although it has significantly lower specific impulse than the

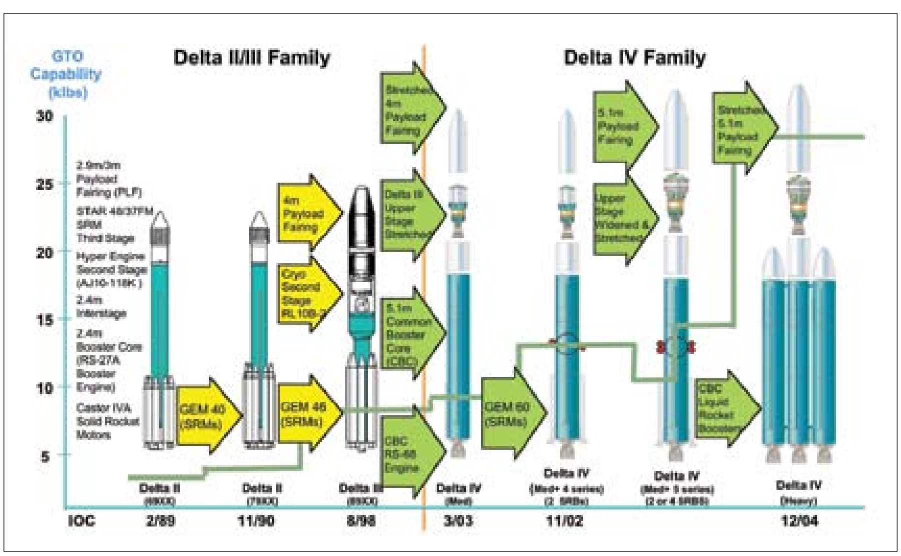


Figure 2. Delta IV Vehicle Family Evolution.

SSME, it produces almost twice the thrust and is much simpler and cheaper to produce.

The complete Delta IV family includes three classes of vehicles—medium, medium plus, and heavy. The medium vehicle comprises a common booster core and a four-meter-diameter payload fairing. The medium-plus vehicle includes a version with a four-meter-diameter payload fairing and two solid motors, as well as a version with a five-meter-diameter fairing and two or four solid motors. The heavy-lift vehicle, similar to Atlas V, consists of three cores strapped together. The Delta IV medium can lift 3,900 kilograms to geosynchronous transfer orbit, while the medium-plus variants can lift 4,535–6,395 kilograms and the heavy lift vehicle can carry up to 12,340 kilograms.

Standard Payload Interfaces

Along with the improvements in performance, reliability, and operability, one of the most significant achievements of the EELV program was the development of a Standard Interface Specification (SIS) for all EELV payloads.[4] The SIS was developed by a joint government-industry team with representatives from launch vehicle and space vehicle programs, and Aerospace serving as the technical arbiter and editor. The SIS includes more than 100 requirements for all aspects of the LV/SV interface including not only mechanical and electrical interfaces, but also mission design requirements, flight environments, and ground interfaces and services.

While a rigorous mission integration process is still required, spacecraft that adhere closely to the SIS can greatly simplify the integration process. The SIS facilitates the dual integration of payloads to fly on both the Delta IV and Atlas V, and also eases the transition of a spacecraft from one payload class to another. The fact that both Delta IV and Atlas V provide the same standard interface is a significant improvement over the heritage systems. To date, four satellite programs will fly on both Atlas V and Delta IV launch vehicles: Wideband Gapfiller Satellite (WGS), Defense Meteorological Satellite Program (DMSP), GPS IIF, Advanced Extremely High Frequency Communication (AEHF).

The Launch Verification Process

In order to implement an independent mission assurance process on EELV, The Aerospace Corporation was asked to employ the process used for over 40 years on heritage programs to determine launch system flight readiness.[5] However, since this process had not been in place during the design review phase of the program, Aerospace developed a tool in the form of a Launch Verification Matrix to prioritize the process and its evolution beginning with the first Air Force launch.[6]

The Aerospace approach to launch readiness verification is unique in its breadth and depth. This comprehensive, end-to-end process extends from concept and requirements definition through flight operations. It entails the detailed scrutiny of hundreds, if not thousands, of components, procedures, and test reports. It draws upon independently derived system and subsystem models to objectively validate contractor data. It provides timely review through firsthand involvement in all aspects of the launch campaign. It concludes with a thorough postflight assessment using independent analytical tools and independently acquired telemetry data to generate useful feedback and monitor performance trends.

Planning and Management – The Launch Readiness Verification process is managed using the above mentioned Launch Verification Matrix. The Matrix is a detailed planning and ex-

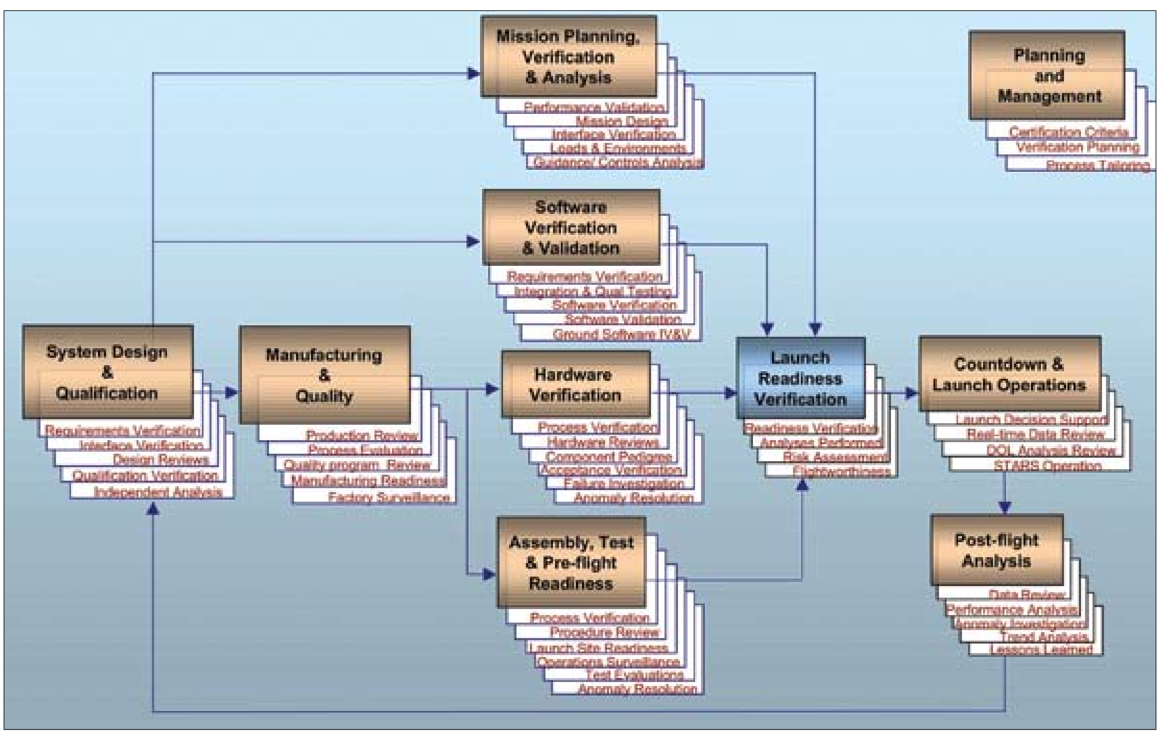


Figure 3. Aerospace Launch Readiness Verification Process. This comprehensive, end-to-end process extends from concept and requirements definition through flight operations.

ecution management tool developed to identify, prioritize, assign, schedule, track, and close as many as 2,000 individual tasks for each mission. Responsible engineers are assigned to assure the successful completion of each task as required by the launch campaign. The management accountability process entails three internal readiness reviews culminating in an Aerospace President's Review prior to the Flight Readiness Review (FRR).

System Design and Qualification – The Aerospace Launch Readiness Verification process begins by verifying that overall top-level performance requirements are properly supported by lower-level systems and subsystems. Independent analyses validate system designs including dynamic loads and clearances, structural margins, thermal protection, and control stability. Design engineers verify that system, subsystem, and component qualification requirements provide adequate margins.

Manufacturing and Quality – The manufacturing process is reviewed to ensure that it can produce the final design. Quality-control processes are checked for compliance with standards and requirements. After reviewing the results of initial production, Aerospace provides technical support to resolve problems with manufacturing techniques. This support can entail in-plant review of hardware and processes.

Hardware Verification – Even before hardware can be screened for defects, acceptance test plans and procedures must be reviewed to ensure that the test environments and pass/fail criteria can be trusted to screen out faulty components. Aerospace responsibilities in this area include witnessing selected acceptance testing of critical items and reviewing anomaly reports and corrective actions. Aerospace personnel also monitor failure investigations, and, in certain critical cases, augment them with independent investigations, which can include metallurgical analyses, material compatibility checks, electronic component testing, and contamination assessments. One particularly important task is the hardware pedigree review, which focuses on individual components and subsystems to establish that they were built and tested to specification.

Figure 4. Aerospace personnel provide countdown and launch support via the Spacelift Telemetry Acquisition and Reporting System (STARS) facility. From this center at corporate headquarters in El Segundo, California, launch engineers have access to a historical flight database using special computer and software tools, allowing independent evaluation of trends and mission-to-mission performance.

Software Verification and Validation – Every space launch requires mission-specific software that contains the instructions needed to get the payload from the launch pad to its intended orbit. Aerospace conducts an independent validation and verification of critical system software, especially pertaining to guidance, navigation, and control.

Mission Planning, Verification, and Analysis – Mission design analysis provides assurance that the launch system is capable of delivering the specific payload to its planned orbit with sufficient margin to guarantee mission success. Aerospace performs an independent analysis to verify adequate mission planning for all flight conditions. The mission analysis establishes that the flight trajectory and parameters are optimized for the specific payload, satisfy flight and safety constraints, and provide adequate performance margins for the radio-frequency link, power, propellant, and consumables. Dynamic loads must be analyzed to verify booster capability and compliance with the interface control document. Guidance, navigation, and control performance must also be analyzed for acceptable injection accuracy and control stability.

Assembly, Test, and Pre-Flight Readiness – At the launch site, numerous tasks must be accomplished to prepare for launch. Aerospace assesses these processes to establish that they adequately support mission readiness and satisfy design requirements and operational constraints. Critical tasks and tests are witnessed and evaluated for compliance with requirements and procedures. Particular attention is placed on anomaly identification and resolution. Aerospace personnel support all major launch site tests and readiness reviews, and provide technical corroboration for the test team.

Launch Readiness Verification – When all procedures have been properly documented and all test results and corrective actions fall within acceptable levels, Aerospace can give its launch readiness verification to the Air Force's Space and Missile Systems Center (SMC). The assessment culminates in a flightworthiness determination and certification by SMC at the FRR. The objective is to ensure that the primary contractors, The Aerospace Corporation, the spacecraft program office, and the launch programs agree that the launch vehicle and payload are ready to begin final launch operations.

Countdown and Launch Operations – Aerospace personnel are on-station during countdown and launch, supporting launch decisions with the knowledge and experience gained during the launch verification process. Day-of-launch support also entails an independent review of launch placards, countdown anomalies, deviations and workarounds, and launch constraint violations. Any anomaly or deviation observed up until liftoff may result in

a reassessment of the vehicle's launch readiness. If the launch is scrubbed, a new flight readiness assessment may be required before the countdown can resume.

Post-Flight Analysis – Aerospace's responsibility does not end when the launch vehicle finally leaves the pad. In fact, some of the most rigorous analysis happens after liftoff. For example, launch-system flight data are analyzed to independently assess vehicle performance, identify and assess flight anomalies, and update the data archives. Postflight analyses and reconstructions are used to perform trend analyses, capture lessons learned, and provide feedback for the next readiness assessment.

Mission Success – The #1 Priority of Launch Readiness Verification

Aerospace's end-to-end system review is a routine but critical part of every SMC launch. The impartial and independent launch readiness verification provides assurance that all known technical issues have been resolved and that residual launch risks have been identified and assessed. When Aerospace signs off on its launch readiness verification, SMC can proceed with strong confidence in ultimate mission success.

The current success record of 47 consecutive SMC operational space launches is no accident. The reinvigoration of independent mission assurance on the heritage programs was mirrored on the EELV program in time for its first launches. The first missions required a focused, prioritized effort, and adding independent launch readiness verification oversight to the EELV missions has been an incremental process. The SMC commitment to mission success, as evidenced by the thoroughness of the flightworthiness certification process, has created a culture that permeates the readiness process. Aerospace's role is to assure that, through its launch readiness verification process, each launch vehicle is technically sound and the risks are acceptable with maximum probability of mission success.

Notes:

[1] *Space Launch Modernization Plan*, May 1994.

[2] *Space Launch Broad Area Review Report*, November 1999.

[3] Randy Kendall, "EELV: The Next Stage of Space Launch," *Crosslink*, Winter 2003/2004.

[4] *Evolved Expendable Launch Vehicle Standard Interface Specification*, version 6.0, 15 August 2000.

[5] E. J. Tomei, "The Launch Verification Process," *Crosslink*, Winter 2002/2003.

[6] Ray F. Johnson, "Independent Launch Readiness Verification on the EELV Program," Conference on Quality in the Space and Defense Industries, (proceedings, March 2002).

Mr. Ray F. Johnson (BS, Mechanical Engineering, University of California at Berkeley; MBA, University of Chicago) is vice president of Space Launch Operations with The Aerospace Corporation. Mr. Johnson is responsible for Aerospace support to all Air Force launch, range and satellite control programs, including Titan IV, Delta II, Atlas II, Upper Stages, the Delta IV, and Atlas V Evolved Expendable Launch Vehicles (EELV), the Spacelift Range, and the Air Force Satellite Control Network. He has responsibility for the company's launch operations at Cape Canaveral, Florida and Vandenberg AFB, California. He also is responsible for the management of civil and commercial contracts involving launch operations.

Mr. Johnson joined Aerospace in 1987 as a project engineer in the Titan program office. He was promoted to manager of the Liquid Propulsion section in 1988. He was director of the Centaur Directorate within the Titan program office from 1990 to 1993 and was responsible for Aerospace's support in developing the Centaur upper stage for use on the Titan IV launch vehicle.

In November 1993, Mr. Johnson was appointed principal director of the Vehicle Performance Subdivision, Engineering and Technology Group, with responsibility for engineering support in the areas of propulsion, flight mechanics, fluid mechanics, and launch vehicle and spacecraft thermal analysis.

Before being named vice president, Mr. Johnson was general manager of the Launch Programs Division with responsibility for managing Aerospace's technical support to the Air Force for the Titan, Atlas, and Delta launch programs.

Mr. Edmardo "Joe" Tomei (BS and MS, Aerospace Engineering, University of Michigan and University of Southern California) is the Chief Engineer for space launch programs with The Aerospace Corporation responsible for technical insight and support to all space launch activity within the company. These have included Titan, Atlas, Delta, and Shuttle launch programs for the Air Force and NASA, as well as a variety of other launch systems. He has been involved in all Air Force launch activity in the past 15 years and also recently supported the Space Launch Broad Area Review, the Columbia Accident Investigation Board and Shuttle return to flight activities.

Mr. Tomei was formerly Chief Engineer for the EELV Program, director of advanced plans and studies, manager for development and launch operations on the Air Force Shuttle Program, and Launch Engineer for NASA/GSFC on the Delta Program. He has over 38 years of experience in launch operations, launch vehicle design, systems engineering, launch system safety, propulsion systems, range safety and operations, and launch vehicle explosive hazards.

Mission Assurance = Assured Access to Space The Recipe for Success

Col Jack Weinstein, USAF
Commander, 30th Space Wing
Vandenberg AFB, California

Space is essential to today's military operations and is absolutely critical to the fight, especially considering the world in which we live and the enemies we face. Simply stated, without the entire launch-base team, on-orbit satellites capable of providing our Nation's leaders and decision-makers with timely, relevant, and accurate information that saves lives and defeats our enemies would not be possible.

Teamwork and the value of the launch-base team provides assured access to space. Even though recent success stories like the fly-out of Titan IV National Reconnaissance Office (NRO) B-26 in October of 2005 and the inaugural West Coast launch of the Delta IV NRO L-22 this past June suggest that space launch is a seemingly routine process; in reality, it remains the highest risk phase in a satellite's life cycle.

Figure 1. Titan IV NROB-26 Mission, 19 October 2005.

Make no mistake; there is nothing routine about space launch. It is still, in fact, rocket science that demands flawless attention to detail and the highest degree of safety, security, and technical standards. We have come a long way in the progress that we have made and a large portion of that progress was a direct result of the 1999 Broad Area Review (BAR).

As a result of launch failures in the 1990s to include engineering, workmanship, and manufacturing issues, the Secretary of Defense directed that the Air Force examine the problem and recommend changes that would prevent such failures in the future. In addition to this tasking, the Secretary of the Air Force and the Air Force Chief of Staff directed Air Force Space Command and the NRO to establish a BAR to assess causes of failure and recommendations for changes in practices, procedures, and operations.

The BAR examined launch activities from 1985-1999 including Atlas, Delta, and Titan, as well as the transition to the Evolved Expendable Launch Vehicle (EELV); Atlas V and Delta IV. The BAR charter addressed the need for an in-depth examination of government and commercial launch failures and recommendations to improve launch mission success. At that time, there was a need to assure mission success in heritage programs due to the fact that over $15 billion in assets were slated for launch on those vehicles. Concurrently, the launch community needed to prepare for a seamless transition to EELV.

Figure 2. Delta IV NROL-22 Mission, 27 June 2006.

The report concluded that engineering and workmanship deficiencies contributed to three Titan IV-related government space launch failures totaling nearly $3 billion in losses. Further mishaps across the board, to include the devastating 1997 Delta II NAVSTAR GPS IIR-1 Class A mishap, prompted an in-depth review of the failures and actions taken to prevent future mishaps. As part of the assessment, the BAR examined the complete launch process and recommended changes in practices, procedures, and operations.

Although the overall Department of Defense assessment contained 19 recommendations from the BAR that applied to both current programs and future EELVs, five key issues were addressed:

1. The government must ensure industry acts to correct causes of recent failures and improve systems engineering and process discipline;
2. The government must define clear accountability for mission success for remaining launches and transition to EELV;
3. The government and industry partnership must be enhanced with increased management, engineering support and emphasis on mission success;
4. The government should complete a well-defined, coordinated and disseminated transition plan to EELVs; and
5. The government should build confidence in EELV reliability with enhancements and increased oversight.

Given the unprecedented string of successful launches since the BAR, it is reasonably safe to conclude that the recommendations provided in the review, most importantly, government oversight and continuous, relentless involvement in the space launch process provided the answers needed to ensure assured access to space. The foundation of space launch mission success is mission assurance. At the launch-base, the wing's mission assurance efforts hinge on a team of blue-suit, contractor, and civilian space launch professionals integrated into the overall space launch campaign. Ultimately, I believe, it is our people and their renewed mission focus that brought us to where we are now and continue to provide our Nation's assured access to space.

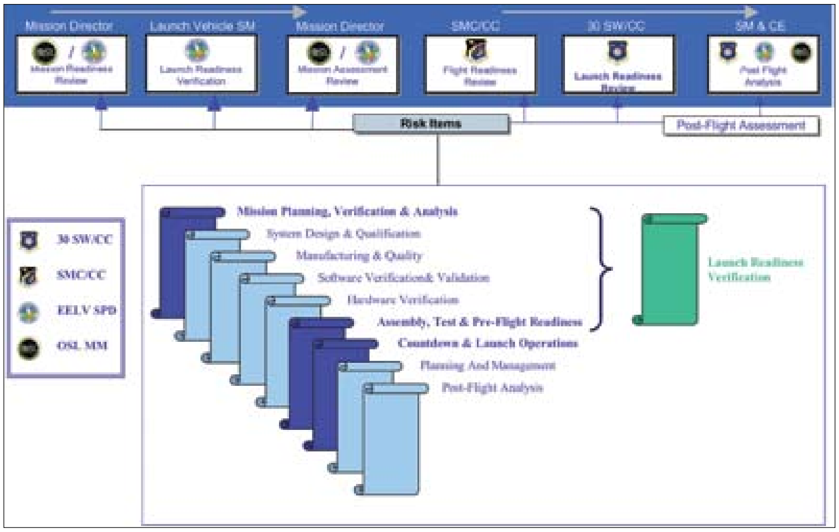


Figure 3. Launch Verification Process.

With the phase-out of the highly successful Titan program and earlier Atlas variants, our two new EELVs are the Atlas V and Delta IV. The Delta IV medium possesses a single common booster core, a modified Delta III second stage, and is capable of launching 9,285 lbs. to geosynchronous transfer orbit whereas the Delta IV heavy is capable of launching 28,950 lbs. to geosynchronous transfer orbit. The Atlas V uses a single-stage Atlas main engine, a common booster core with up to five strap-on solid rocket motors, and is capable of launching over 19,000 lbs. to geosynchronous transfer orbit depending on the configuration.

One component of mission assurance with respect to EELV and these vehicles is integrated risk assessment and mission assurance for launch stakeholders. The Air Force Space Command (AFSPC) 1200-series governing directives include launch and range roles and responsibilities (AFSPCI 10-1208), spacelift launch strategies and scheduling procedures (AFSPCI 10-1213), and support to commercial space launch activities (AFSPCI 10-1215). The launch-base team implements AFSPC policy for launch and range roles, responsibilities, strategies, scheduling procedures, and support to commercial space launch activities. Similarly, EELV mission assurance is covered under Space and Missile Systems Center (SMC) 1200-series instructions to include Assurance of Operational Safety, Suitability, and Effectiveness for Space and Missile Systems (SMCI 63-1201), Space Flight Worthiness (SMCI 63-1202), the Independent Readiness Review Team (SMCI 63-1203) and the SMC Readiness Review Process (SMCI 63-1204).

The launch-base team takes this guidance one step further through the implementation of local operating instructions and critical activities that offer risk assessment of launch processing activities and guidance, as necessary, to the contractor team. The launch-base team provides on-site risk management delegated through the Launch and Range Systems Wing. The mission assurance activities and milestone reviews are illustrated in figure 3.

The blue bar indicates specific milestone reviews or points in the process that ensure system components are ready as stated in the SMCI 63-1200-series EELV Operational Safety, Suitability and Effectiveness Assurance Process. It is important to note that the review authorities differ depending on the mission. For example, the NRO chairs the Mission Readiness Review for NRO payloads. Similarly, the Commander, Launch and Range Systems Wing, chairs the Mission Readiness Review for other government launches.

The dark blue scrolls indicate the portions of the Launch Verification Matrix (LVM) that the launch-base team is tasked to assess; specifically, mission planning, verification and analysis, launch site assembly test and pre-flight analysis, and finally, countdown and launch operations. Without a doubt, the launch-base team is an absolutely critical piece of the entire process, something identified by the BAR and proving more and more relevant as space launch missions continue to be rocket science and continue to launch one-of-a-kind satellites that can cost over a billion dollars.

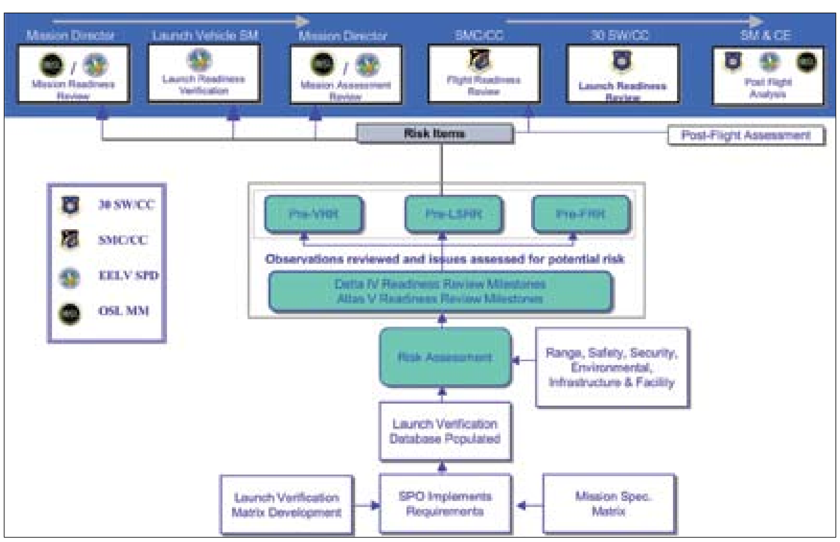


Figure 4. Launch Verification Process.

In addition to the launch-base team, our engineering and acquisition space professionals take the LVM and analyze the processes

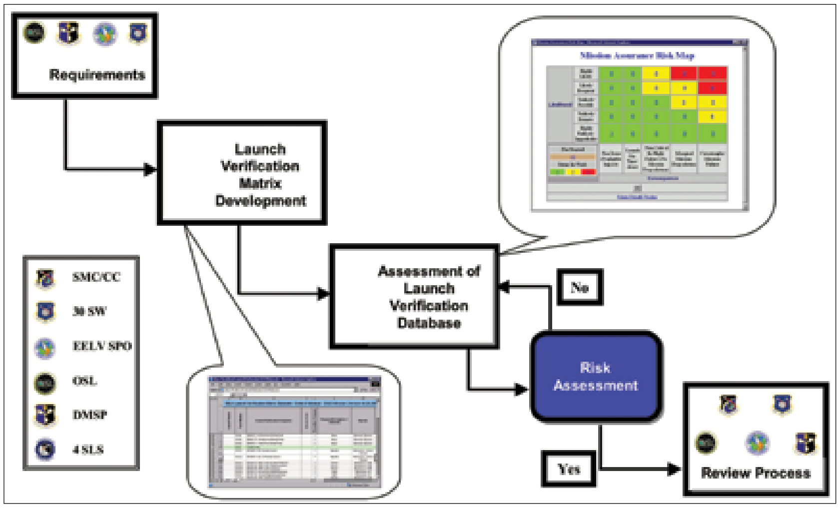


Figure 5. Operational Safety Suitability and Effectiveness.

in order to ensure that a cognitive assessment of the necessary tasks are, in fact, accomplished on the pad to ensure mission success. Technical experts such as material and electrical engineers analyze the specific requirements and see to it that the right level of testing is performed at each step. At the same time, our acquisition professionals analyze all the requirements from both a contractor and Air Force perspective to ensure that all obligations are fulfilled. As the campaign progresses, our engineers and acquirers are responsible for the inputs from the pad, ensure the correctness and completeness throughout the process, and work with the launch-base team and the Launch and Range Systems Wing to clarify, mitigate, or upchannel status as necessary.

Risk analysis and status is a fundamental input into the review process. The Launch Verification Process assists in the risk analysis process by providing a forum for the launch-base team to provide inputs in support of the various reviews. The launch-base team utilizes the LVM to populate an information source known as the Launch Verification Database (LVDB) to perform, document, and track risk assessments within the readiness reviews as indicated below. In this case, specifics for Atlas V and Delta IV campaigns are displayed in figure 4.

A top-down approach to risk management begins with the identification of the launch vehicle processes and ends with stated requirements for insight. The LVM provides data used to populate the LVDB, a tool used by the launch-base team to monitor and assess this risk. Risk assessment and management are continuously performed and reported at the review process milestones, as well as on-going risk status forums occurring throughout the major milestones.


Figure 6. Minotaur COSMIC Mission, 14 April 2006.

A second form of launch-base team mission assurance similar to the EELV method of risk assessment is utilized in other spacelift campaigns to include Minotaur and Pegasus. The Minotaur is a four-stage, small-satellite launch vehicle with the capability to lift 750 lbs. to a 400-nautical mile, sun-synchronous orbit. Stages one and two utilize Minuteman II rocket motors while stages three and four employ the Orion 50 XL and Orion 38 Pegasus motors respectively. The basic configuration of the vehicle utilizes the Pegasus fairing to protect the payload.

Similarly, the Pegasus is a three-stage, small-satellite launch vehicle with the capability to lift 620 lbs. to a 100-nautical mile orbit. Unlike any other expendable space launch vehicle, the Pegasus utilizes the L-1011 aircraft for the initial phase of flight. At approximately 40,000 feet, the vehicle is released from the belly of the aircraft, free-falls for several seconds, and ignites stage one for the initial acceleration to orbit. Mission assurance for both Minotaur and Pegasus involves executing a procedure review, documenting via database inputs, tracking procedures, monitoring operations, and ensuring the government and contractor mission assurance teams work together.

Spacelift mission assurance can be thought of as a system of processes that provide rigorous, continuous, cradle-to-grave assessment, validation, and verification of requirements at the part, component, and system levels to minimize risk, assure adequate margins and, improve the probability for mission success. Both the EELV and Minotaur/Pegasus mission assurance components rely on a blue-suit, contractor, and civilian team dedicated to the flawless accomplishment of the mission.


Figure 7. Pegasus Space Technology-5 Mission, 22 March 2006.

Our enlisted space professionals, experts in missile systems maintenance, are key factors in the relentless pursuit of mission assurance. These men and women provide the eyes-on, detailed assessments of the work occurring at the space launch complex and on the space launch vehicle. Our Airmen serve as the critical link between pad operations and the entire mission assurance process. They possess the knowledge, skill-set, and discipline required of spacelift operations and provide the direct link between launch pad operations and leadership to ensure technical issues and government interests are kept at the forefront.

These sterling professionals perform several categories of mission assurance. First, they perform infrastructure management to include sustainment and program integration for spacelift facilities and act as the point of contact for facility and range

Figure 8. Delta IV NROL-22 Mission Assurance (left to right) SSgt Mark Rische, TSgt Roy Heichelbech, and SSgt David Smith (4th Space Launch Squadron).

communication-related issues. Second, they perform environmental management to ensure that launch-base programs comply with all applicable environmental regulations. Lastly, and most importantly, they ensure compliance with all applicable safety regulations and ensure all personal and flight hardware are safe at all times.

They also perform critical tasks throughout the entire booster process. For Minotaur missions, they conduct booster transport and emplacement, and perform contractor surveillance throughout the entire campaign. Additionally, they provide an experienced maintenance perspective for government program management status and consideration. Finally, with regard to EELV missions, they review processes for correctness and ensure that the tasks are not only accomplished, but accomplished flawlessly.

Cradle-to-grave mission assurance occurs between the launch-base team and SMC with our enlisted space professionals on the scene at the Defense Meteorological Satellite Program (DMSP) program office, and providing eyes-on mission assurance at the Lockheed Martin DMSP factory in Sunnyvale, California. During these visits, they act on behalf of the commander of the DMSP Systems Group and attend all meetings and reviews. During processing at the launch-base they provide mission assurance through observation. They execute squadron tasks to meet wing responsibilities delegated from programs that require a system-level perspective unable to be efficiently subdivided. Finally, they provide launch site surveillance, monitor processing and integration tasks, identify risk areas, assign risk assessment, recommend corrective actions, and determine launch-base processing tasks.

Eyes-on, aggressive oversight from cradle-to-grave, from the engineers to the acquirers to the maintenance technicians must be continuous, it must be perfect, and it must not stop there. Integration must now occur with the launch-base range team. The range team will assess all outstanding risk and develop/execute procedures accordingly from the initial campaign kick-off meeting, which focuses the entire contractor, blue-suit, and civilian launch team on the tasks, requirements, and issues for the mission, to the launch readiness review where processes and procedures are affirmed prior to launch. Operators such as the mission flight control officer, the range control officer, and the range operations commander follow each and every step with precise, focused discipline delivering the level of perfection necessary to ensure public safety and mission success.

Range instrumentation, telemetry, radars, digital transponders, and all other assets are precisely calibrated to exact specifications for the rocket on the pad. Finally, the Air Force launch director takes everything submitted to this point and conducts a symphony of processes, checklists, and coordination thereby ensuring that everything is complete, ready, and in-place for mission success. The countdown and subsequent successful launch, while vitally important and impressive to watch, is just the tip of a very long process; mission assurance begins years earlier.

An unprecedented string of success has led us to where we are today. Our Nation is stronger, our military members are safer, and our space capabilities are providing cutting-edge, state-of-the-art imagery, and communications like never before. To say that mission assurance is important is an understatement. It is the only way to achieve mission success. Government oversight of the entire space launch process to include on-scene technical advice and risk assessment by the launch-base team is absolutely critical to the overall success of space launch and the insertion of payloads into proper orbit.

One set of eyes is not enough, we tried that in the 1990s and it led to disaster. Whether it is an honest mistake on the pad or a known shortcut by someone, somewhere in the process, the fact remains that we only get one chance to do it right. There are over a million items that need to be perfect in order for a launch to happen. Mission assurance is the integrity that we provide the American people so that when we launch, the satellite is going to get into orbit. As a nation, we don't build back-up satellites. If we fail on launch, we fail on the battlefield and that is simply unacceptable. We have to be successful, the warfighter depends on it. Mission assurance, through intellect and discipline, is the only way we as a space community will be able to both sustain and guarantee mission success now and into the future.

Col Jack Weinstein (BS, University of Lowell; MS, Embry-Riddle Aeronautical University; MS, Industrial College of the Armed Forces) is the 30th Space Wing commander, Vandenberg AFB, California. Colonel Weinstein leads the wing's launch, range, and expeditionary missions. Additionally, the wing provides infrastructure and testing support for Missile Defense Agency ground-based interceptors. He has served on the Headquarters Air Combat Command, Air Force Space Command, and United States Strategic Command staffs. His operational assignments include MMIII combat crew, 321st Missile Wing, Grand Forks AFB, North Dakota; operations officer, 12th Space Warning Squadron, Thule Air Base, Greenland; Commander, 2nd Space Warning Squadron, Buckley AFB, Colorado; USSTRATCOM Senior Controller, Offutt AFB, Nebraska, and Commander, 90th Operations Group, F.E. Warren AFB, Wyoming. Prior to his current assignment, Colonel Weinstein was the CENTAF Director of Space Forces. Colonel Weinstein is a distinguished graduate of ROTC, MMIII initial qualification training, and Air Command and Staff College.

The Power of Partnership Assuring Access to Space

Col James O. Norman, USAF
Director, Office of Space Launch
National Reconnaissance Office

A History of Partnership

The partnership between the Air Force (AF) and the National Reconnaissance Office (NRO) Office of Space Launch (OSL) in the area of space launch is decades old. During its time as a covert organization, the AF element of the NRO acquired launch vehicles for NRO satellites via AF contracts and shared funding responsibility for many launch vehicle infrastructure requirements. This is a partnership practice that continues today. This arrangement allows the AF and the NRO to leverage the strengths of both without unnecessary duplication and allows unparalleled focus on mission success. For instance, the NRO funds half of the Aerospace Corporation Federally Funded Research and Development Center resources (hundreds of man hours) used by the AF booster system program office (SPO). This is an agreement with historical roots. It benefits both the AF and the NRO ensuring the appropriate amount of Aerospace Corporation expertise can be brought to bear for launch system analysis. The AF–NRO partnership has worked exceptionally well since the late 1990s, following the three Titan failures in 1998. Since that time, the AF and NRO working together have launched 42 consecutive missions successfully, including the last of the Atlas IIAS, the Atlas IIIB, and the Titan IV systems. They continue to work together as they make the transition to the Evolved Expendable Launch Vehicles (EELVs), namely the Lockheed Martin Atlas V and the Boeing Delta IV families. With Titan gone, these are the Nation's current medium- to heavy-lift fleet providing assured access to space for our National Security Space (NSS) missions. As we go forward under EELV, the NRO will continue to fund half of the Aerospace Corporation launch support and will also provide 30 percent of the EELV launch capability funding for Atlas V and Delta IV. Evidence of this partnership's success is our most recent mission, NRO Launch-22 (NROL-22), the first NRO launch on the Delta IV booster. The launch was also significant in that it was the first NSS mission from Space Launch Complex (SLC) 6 and the first EELV launch from Vandenberg AFB, California. During this launch campaign, the NRO, the AF, and our contractor teammates worked a number of significant issues collaboratively, bringing the required technical expertise to bear to ensure resolution of these issues leading to the launch of NROL-22 on 27 June 2006. This article outlines the NRO/OSL philosophy of mission assurance and contains examples of how the partnership performed flawlessly during the launch campaign. The magnitude of this mission's success with an all-cryogenic booster, the effort required to integrate a critical NRO payload on a new booster, and the act of launching from a pad that had never before been used cannot be overstated and are collectively a tribute to the hard work and teamwork of the entire government and industry team that made it happen.

Liftoff of NROL-22 from Space Launch Complex 6—the first EELV launch from Vandenberg AFB, California.

A National Reconnaissance Office Perspective on Mission Assurance

NRO satellites are state-of-the-art, hard-to-launch, fragile, and demand the most strenuous environmental and cleanliness requirements. Each satellite is a handcrafted technical marvel. Hundreds of thousands of hours are expended to painstakingly build, stitch, tape, glue, screw, and engineer a symphony of moving parts, precise optics, software, amplifiers, receivers, payload and antenna deployments, and solar array movements. Years of subsystem and system testing assure conformance to rigorous technical requirements. Industry standards for manufacturing, safety, parts accounting, quality, and reliability are tracked. The goal is to advance the state-of-the-art and the collection capability with each satellite, not simply build a copy of the last one. Very early in the mission concept design phase—as early as five to ten years prior to launch—the NRO/OSL is engaged with an NRO satellite SPO to ensure launch aspects are a part of the spy satellite's system design trades. This effort is not only focused on the booster, but also on issues such as payload transport from factory to launch-base, payload processing while at the launch-base, and required modifications to the launch-base infrastructure if needed. Once the system is defined and authority to proceed is granted, the exhaustive process to integrate satellite and launch vehicle begins. Usually, a multi-year process, all elements of flight design, vibro-acoustic loading, aerodynamics, shock, and so forth, are taken into account to ensure the launch vehicle does not break the satellite during ascent. Then on launch day, the satellite is consigned to nothing short of a controlled explosion as it is lofted hundreds or thousands of miles into orbit. And this

Dusk ascent of NROL-22 seen from Castaic Lake, California (approximately 115 miles east of Vandenberg AFB, California).

is exactly the point—how does one transport the world's most complex and expensive satellites while on the Earth and then off the Earth and into orbit? The answer is use of a rigorous mission assurance process that is smart, innovative, exhaustive, meticulous and, yes, costly. One can think of it as insurance on the investment. If billions of dollars are invested in a satellite, it is prudent to also do everything possible to ensure it is delivered to its proper destination undamaged.

Launch is a high-risk operation. In fact, launch is by far the highest-risk event in the life of any satellite. It is correct to say that a thousand miracles must occur simultaneously for a satellite to successfully defy Newtonian physics and arrive safely in orbit. The spectacular launch mishaps of the past bear sober witness to the failure of any one of these miracles to occur.

Fundamentally, NRO mission assurance processes focus on risk *management*, not risk *elimination*. Painstaking risk identification activities early in the launch integration process catalog risks and risk management plans are developed to retire them early. Nice words, but what does it really mean?

First, "pedigree" reviews are conducted on flight-critical hardware items. This means an intensive review must first be done to identify those flight hardware items deemed "critical." The NRO/OSL, AF, and industry partners meet early in a mission's life to define what these flight critical components are. Then the NRO/OSL funds the AF booster SPO to perform those reviews. Pedigree reviews require that technical teams visit the factory floors where these components are manufactured. As-built drawings are reviewed and actual production hardware is examined to ensure critical hardware has been built to proper specifications.

Second, robust systems engineering processes must be in place to ensure configuration changes to the launch vehicle fleet—a fact of life—do not add technical risk to a specific mission. Rocket engine upgrades, avionics improvements, propellant breakthroughs, and so forth, may have marked sub-system level benefits; but the unintended consequences on other systems may prove deleterious. Good systems engineering ferrets out these ticking time bombs before cataclysmic mistakes propagate. Again, the NRO/OSL chief engineer's office works with and relies on AF booster SPO teammates to be the first line of defense for this critical systems review activity.

Third, an *independent* team of highly competent technical experts reviews any booster non-conformances identified during the launch vehicle build, transport, or pre-launch testing. In the NRO, these technical experts are known as the Mission Assurance Team (MAT). *Independence* is key. The MAT reports directly to the NRO mission director—not the launch vehicle program office or the chief engineer—and is tasked with identifying the mission risk of "out of family" or "out of spec" conditions. This team is not tasked with analyzing or fixing the problems they discover—that is the job of systems engineering. Instead, the MAT provides in-depth assessments of the problem couched in terms of launch risk. Again, paramount to the MAT's effectiveness is its *independence*. If it becomes part of the solution process, it loses its independence.

Fourth, Independent Verification and Validation (IV&V) of mission software, loads analysis, acoustics breakdown, vibration and shock environments, propellant slosh models, mass properties calculations, and so forth, are performed to ensure the quantifiable elements of mission design are fundamentally sound. The IV&V plan is conceived approximately two years before launch and finalized 12 months prior to launch, and could include up to 1,000 items. IV&V is different for each mission; for instance, if a mature, well-understood launch vehicle is used, less IV&V is required. However, the current family of EELVs is not fully mature. Thus, IV&V serves as a hallmark risk reduction measure.

Finally, the senior review cycle culminates the technical risk management process to ensure all risks are either eliminated, managed to the lowest possible level, or retired as an acceptable risk. This review cycle occurs in one month prior to launch and starts with the launch vehicle contractor's senior review (usually at the vice president or sector president level), proceeds to the Aerospace Corporation president's review, the AF Space and Missile Systems Center (SMC) Commander's Flight Readiness Review, the NRO Director's Mission Certification Review, and concludes with the NRO mission director's day-of-launch Consent to Launch and AF Space Wing Commander's Launch Readiness Reviews. While this process may sound onerous and painfully cumbersome, one must never lose sight of the fact that it is all about the *mission*—not just the launch vehicle, but also the very expensive and highly capable payload being placed into orbit and the incredibly valuable and timely information it will provide to warfighters and national decision-makers. It would be imprudent not to spend the time to ensure all mission risks were examined in detail and dispositioned appropriately. These reviews exercise the risk management process at every level by ensuring all known risks are addressed and mitigation efforts are completed.

Having said all this, it is important to keep in mind that it is virtually impossible to completely eliminate risk from the launch equation. Knowing where to draw the line between acceptable and unacceptable risk can be daunting even to the most experienced launch veterans. However, by "measuring twice and cutting once," NRO launch managers rely on vigorous risk management principles to make launch decisions. Capturing

and managing risk with independent assessments, strong systems engineering, hearty IV&V, and a thorough review cycle offer the best opportunity to string together those "thousand miracles" on day of launch.

The following are examples of this risk management approach applied in partnership with the AF and contractor teammates during the NROL-22 launch campaign that resulted in a perfect launch.

NROL-22 Mission Challenges—Resolved Through Partnering

Upper Stage Liquid Hydrogen Slosh: As the inaugural NRO EELV launch, NROL-22 brought forth many intriguing challenges for the technical community. One such challenge, reaching across a number of disciplines and organizations, was the liquid hydrogen (LH2) "slosh" investigation and resolution. This issue was found two days prior to the original October 2005 launch date when the Analex Corporation, an IV&V contractor, discovered a discrepancy in the propellant slosh behavior resulting from minor mission changes made in the final flight trajectory, which had been provided and analyzed 30 days prior to launch. The upper stage flight profiles of the previous three Delta IV intermediate launch vehicles were very different from the profile required of the NROL-22 upper stage; thus, this was "new ground" for the Delta IV. Analex's analysis predicted the presence of a significant wave of liquid hydrogen inside the upper stage LH2 tank during the passive thermal control maneuver and extended coast phase of the flight as part of their upper stage propellant usage analysis. This issue was presented to the entire government and industry launch team while in the final preparations for the 5 October 2005 launch attempt. The significance of this issue and the potential catastrophic impact was lost on no one on that 3 October afternoon. The unanticipated slosh could have made the upper stage uncontrollable and unable to place the satellite in the proper orbit. Needless to say, the launch service contractor along with the AF and other industry team members recommended we stand down from that launch attempt. As disappointing as that was, it was the right decision because mission success is the top priority. Upon reviewing the slosh results, a team of NRO/OSL, AF, Boeing, Aerospace Corporation, and Analex personnel was established to investigate and resolve the issue for NROL-22. As an added dynamic, Geostationary Operational Environmental Satellite-N (GOES-N), the National Aeronautics and Space Administration's (NASA) weather satellite, was the next Delta IV scheduled to launch, and with a profile similar to NROL-22, the decision was made to address the issue for both missions.

Through the use of multiple teleconferences each week, the team began building a fault tree with inputs from all members of the community. Through the use of resources at Boeing, Aerospace Corporation, and Analex, the fault tree was quickly and efficiently dispositioned. As Boeing worked to implement the suggested solution for GOES-N, Aerospace Corporation and Analex members worked with Boeing to understand how the solution would be implemented for NROL-22. Analysts at Boeing, Aerospace Corporation, Analex, and L-3 Communications

Encapsulated NROL-22 payload being lifted during processing operations at Vandenberg AFB, California.

worked to support the slosh resolution team through trajectory simulations, flight software updates, and improved fidelity and integration of multiple modeling tools. Heeding lessons of the past, the team also undertook the task of ensuring the proposed LH2 slosh mitigation solution did not have unintended consequences for other subsystems. Rigorous discussions ensued between analysts from multiple technical disciplines to ensure that everyone was aware of the new NROL-22 profile and its impacts on other vehicle subsystems and phases of flight. In the end, an engineering review board hosted by Boeing and attended by all affected parties agreed that the proposed NROL-22 profile was the correct way to address the issue at hand. It was implemented as an EELV fleet-wide change for the Boeing Delta IV booster system.

Resolution of the LH2 slosh issue exemplified the benefit of collaboration within the contractor and government launch community. In addition, this effort helped substantiate the value of IV&V in the EELV era and helped foster a foundation of trust between the Delta IV launch vehicle contractor and the NRO- and AF-funded IV&V contractors. With everyone working together, the correct technical decisions were made in a timely manner that supported the mission schedule with corollary benefits to NASA.

Composite Structure Strength: Another technical concern that arose in parallel with resolving the LH2 slosh issue was the discovery of booster composite structure strength concerns. The Delta IV booster has several major composite components, such as the payload fairing, payload attach fitting, interstage, center body, thermal shield, and aeroskirt, so a structural concern was a major risk issue to launch schedule and mission success. Like "slosh," this issue also highlighted the absolute need for teaming and collaboration for timely and correct issue resolution. The issue was found while performing composite material coupon tests at the request of NRO/OSL to verify the strength of composite structures following a composite curing process change. Boeing, the Delta IV booster contractor, discovered an undesirable and unexpected production close-out joint feature not related to the cure cycle process change. The composite coupons with this production close-out joint were breaking at less force than Boeing had anticipated. This new data was terrible news to the entire launch team. The low strength condition created concerns where these close-out joints occurred for the structural margins of safety for the seven composite structures used throughout the Delta IV vehicle. Composites issues are much more critical on the Delta IV than on previous US launch vehicles because the Delta IV is the first US launch vehicle to use composites for multiple major structures in the primary load path of the vehicle.

Boeing assembled a team of structural experts from various Boeing divisions (including their commercial aircraft division) and others from the launch community, including Aerospace Corporation, the AF EELV SPO (SMC/LR), and NRO/OSL. In addition, through its MAT and chief engineer's office, NRO/OSL brought in additional experts to further augment the investigation team. This team worked together to understand the problem, independently verified each other's work, identified a variety of confidence tests that could be performed to determine the true characteristics of the composite, and effectively assessed the design's viability for flight use. A series of new tests was presented to Boeing launch vehicle management, and discussed as an integrated team. The multi-organizational approach to work this issue to conclusion was essential in identifying multiple test options. No single test option could be used successfully, as they all had benefits and weaknesses. However, the combination of the various options resulted in much higher confidence and technical consensus from the community, and provided the solution in a timely fashion to support the June 2006 NROL-22 launch.

Payload De-encapsulation and Re-encapsulation: In addition to the two major booster issues—slosh and composites—a third major issue arose late in the launch flow when it was determined that access to the payload attach fitting was needed. Recall that two days from launch in October 2005, the launch was scrubbed. The payload was demated from the booster and returned to the payload processing facility to provide protection from other launches and the best support environment while work proceeded on booster issues. The satellite was left encapsulated in the payload fairing in order to avoid the handling risk of removing the fairing as well as to maintain the best posture to return the satellite to the rocket at the earliest opportunity. Unfortunately, the previously mentioned composite issue and a new issue related to the payload required a complete de-encapsulation of the payload. The entire NROL-22 team, including NRO/OSL, SMC/LR, the 30th Space Wing (30 SW), the launch vehicle and satellite vehicle contractors, Aerospace Corporation, and Spaceport Systems International (the payload processing facility owner), were challenged to develop and maintain a new integrated schedule to keep the launch on track for 27 June 2006. At no time in the more than four year integration launch flow was a stronger teaming relationship more important than during the resolution of these additional challenging issues.

At approximately three months prior to launch, the NROL-22 integration team was faced with issues that essentially removed any margin from the launch schedule. The challenge: determine how to de-encapsulate the payload, solve the anomalies, and then re-encapsulate to meet the satellite mate date on the Delta IV booster. All of this unexpected, out-of-position work needed to be collectively performed by the entire team on an integrated schedule to determine what resources were needed and by what organization. What work should be done in parallel with the satellite work? What work could be moved later in the launch flow? In addition, Air Force Space Command range assets needed to be rescheduled to support this shifting work, so the 30 SW was a critical member of the team.

The entire integration team successfully scheduled and completed all work required to meet the satellite transport and mate to booster date in early June. NROL-22 was launched on schedule. The team's success in resolving these most challenging issues is a testament to the power of partnership across the space and launch community.

Flight Termination System Batteries: A fourth situation that threatened to impact our ability to meet the 27 June 2006, launch date arose from test results that brought into question the flight worthiness of the Delta IV Flight Termination System (FTS) batteries. During destructive physical analysis after qualification of a new production run of FTS batteries, several wire tabs from the cell plates to the terminal were discovered broken, a condition that could have led to a reduced battery capacity. This finding led 30 SW Range Safety to place a flight constraint against all launch vehicles flying from Vandenberg AFB using these particular FTS batteries. The 45th Space Wing (45 SW) Range Safety placed a similar flight constraint on launches from Cape Canaveral, Florida as well. This lien threatened the launch of several vehicles in the near term including NROL-22.

In response to the multitude of issues building in the time leading up to launch, weekly NROL-22 mission integration meetings were instituted with members from the entire launch team to provide status on current issues. Those making up this group included members from the 45 and 30 SWs, the AF Launch and Range System Program Office (SMC/LR), the launch service integrating contractor (Boeing), the Aerospace Corporation, and several systems engineering and systems integration contractors.

Soliciting participation from all parties proved effective in determining alternate paths to mitigate the high-risk schedule the

Boeing Completes First Delta launch on 27 June 2006. An image of a Delta IV Medium+ (4,2) rocket launching NROL-22 at night.

team faced. Soon it was discovered that there were not enough flight-worthy FTS batteries to support all upcoming missions. The team then decided that the most appropriate course of action was to pursue another FTS battery supplier used by Lockheed Martin. This presented a unique challenge due to the fact that Boeing and Lockheed Martin are competitors in the space launch industry. Nevertheless, a collaborative effort, spearheaded by the SMC/LR SPO Director and supported by the Space Wings and NRO/OSL, led to the establishment of a proprietary information arrangement between Lockheed Martin and Boeing regarding the alternate battery, which, in turn, resulted in the team's ability to pursue this battery as a back-up for the NROL-22 mission.

Boeing, in full coordination with representatives from all stakeholders, developed the plan and procedures for installation and checkout of the alternate batteries. The plan accounted for unique characteristics of the substitute batteries, such as capacity, dimensions, number of cells, weight, wet stand life, mounting requirements, and so forth, that differed from the characteristics of the original batteries.

To further guard against a slip in the schedule and provide maximum flexibility to support the launch date, Boeing was asked to develop several scenarios to determine optimum decision points to incorporate modifications to the Delta IV required for the alternate batteries, as well as to determine the last opportunity to support the launch date should the original FTS batteries be exonerated by range safety.

In summary, it took a creative and innovative team across multiple organizations and geographic regions to overcome the challenge of this situation. All members of the team put the mission first, focusing on what was necessary to get the job done to mitigate and manage risk. Rather than blame each other, the NRO/OSL, SMC, and contractor team developed innovative solutions that provided victory for all parties involved. The end result of AF leadership and NRO/OSL support provided a solid set of FTS batteries for the eventual successful 27 June 2006, launch of NROL-22.

Conclusions

In the words of some of my predecessors, "Launch is hard …" and "Launch work is teamwork." The NRO recognizes the power that partnering brings to the mission success equation. While this article focused on the partnering between the AF and the NRO on Delta IV, there are many other examples that illustrate how valuable the partnership is, not only between the NRO and the AF, but also with NASA. Launch is not a commodity—it is still an engineering exercise fraught with technical risks that must be managed in order to provide the greatest possible assurance for access to space. It is through partnering that mission owners, whether NRO, AF, or NASA, can choose to apply the appropriate levels of mission review and mission assurance to meet their mission needs. The NRO looks to partner with the AF and industry to deliver world-class satellites to the proper orbit.

Contributing Authors: Col John Stizza, Maj Keith Kosnic, Capt Eric Zarybnisky, Capt Ben Brown, and Mr. H.J. Garnand.

Col James O. "Jim" Norman (BS, Human Factors Engineering, US Air Force Academy; MS Business Administration, Central Michigan University) is Director, Office of Space Launch, National Reconnaissance Office (NRO), Chantilly, Virginia. Colonel Norman is the Mission Director for all NRO launches and is responsible for the programming and acquisition of NRO launch vehicles, launch vehicle integration, transport of satellites, launch-base processing, and infrastructure support for NRO payloads. He is a 1983 US Air Force Academy graduate. He has a broad background in systems engineering and acquisition program management of airborne and space-based reconnaissance systems from tours of duty with the SR-71/U-2 Program Office and previous tours with the NRO. He performed space operations duties while assigned to the DoD's Aerospace Data Facility at Buckley AFB, Colorado and served in space-related staff positions for the Director of Central Intelligence at HQ CIA, and in the Pentagon for the Assistant Secretary of the Air Force (Space) and the Under Secretary of the Air Force. Colonel Norman is a 2001 Air Force Fellow and attended the International Security and Military Affairs Program at the Mershon Center on the campus of The Ohio State University in Columbus, Ohio for Senior Developmental Education.

Toward Responsive Space Access

Brig Gen Susan J. Helms, USAF
Commander, 45th Space Wing

Recent conflicts have demonstrated the unprecedented advantages our space capabilities provide to military commanders. As a result, our Nation's dependence on these space-based capabilities continuously grows. Lt Gen Frank G. Klotz, Vice Commander, Air Force Space Command (AFSPC), points out, "Space is not just important, but critical to the very nature of both our military strength and our society as a whole, and the idea of space being more responsive is unquestionably a necessity."[1] The need for additional bandwidth to support critical communications or the requirements for persistent imagery over multiple 'hotspots' in the world are examples of "on-demand," space-based capabilities that have direct value to the warfighter. The unexpected loss of a critical space capability and/or the inability to replenish capability when required can be viewed as a potential vulnerability for our Nation. And if a new satellite launch campaign is part of the delivery process, delays in the delivery of those effects to the combatant commander can be protracted over months or years. When facing a future where space itself can become a battlefield, the agility of our Nation to supply and replenish critical resources on-orbit demands a more responsive launch posture than has been the case in the past.

The urgency behind fielding such a posture is evidenced by the January 2005 US Space Transportation Policy which directs, "Before 2010, the United States shall demonstrate an initial capability for operationally responsive access to and use of space to support national security requirements."[2] But we cannot wait for long-term technology breakthroughs to address the issue. Rather, every aspect of space, including our existing launch capabilities, should be analyzed for potential improvements in current responsiveness. An evolutionary move toward responsive spacelift forms the basic building blocks to support the Nation's capability to promptly, accurately, affordably, and decisively position and operate national and military assets in and through space.

Figure 1. First Delta IV Launch—Cape Canaveral AFS.

Historically, our early space access vehicles have been inherently unresponsive. Their design, manufacture, processing, and launch were characterized by time-consuming pathfinder processes and lengthy test, checkout, and launch operations. Conversely, a mature responsive space access capability that realizes a delivery goal measured in hours or days is at the opposite end of the continuum. Currently, we operate between those two extremes at the Eastern and Western launch ranges. To move forward toward a significantly more agile launch posture, an operationally responsive space access program seeks to address the need for a more agile launch posture through strong focus on four complementary elements: design of the lift vehicle, design of the satellite, support of responsiveness through infrastructure and support concepts, and a responsive launch range.

A More Responsive "Booster"

Fundamentally, the launch vehicle's design determines its inherent flexibility and thus its responsiveness. A complex launch vehicle requires more transportation/hosting, assembly/re-assembly, testing/retesting, monitoring, and verifications to ensure it will function precisely as designed. The Titan IV was the pinnacle of the intercontinental ballistic missile-based launch vehicle system's evolution. From its humble roots as the Titan I through more than 360 space launches, the Titan launch vehicle was modified, molded, stretched, and strapped onto in an attempt to squeeze every ounce of performance allowable by the laws of physics. The last East Coast Titan launch in April 2005 was historic and a tribute to its success as the workhorse that helped to bring down the Soviet Union. With a 548-day launch flow, it also served as an example of our inability to rapidly respond to the dynamic needs of a new era. The Titan IV was not designed, but rather redesigned to carry high-cost satellites, and there was a price to pay in responsiveness.

Conversely, a less complex and more robust vehicle allows for minimized testing and verifications, thus reducing processing timelines. The trend of extensive booster processing was finally turned around with the development of the Evolved Expendable Launch Vehicle (EELV), the first family of launch vehicles designed from the ground up specifically to put satellites into operational orbits rather than throw a warhead halfway around the world on a ballistic trajectory.

The EELV Atlas V and Delta IV designs capitalize on decades of lessons learned and the availability of state-of-the-art materials, manufacturing techniques, and computational analysis to significantly reduce piece parts and increase inherent reliabilities. With these improvements came a more robust design that can be assembled off line at the factory and requires fewer launch site verification tests. By comparison, the last two Titan IV mission processing flows (Titan IV B-39 and Titan IV B-30) from Cape Canaveral, Florida—from first hardware arrival through launch—lasted 122 days and 548 days respectively, while the most recent EELV Atlas V processing flow lasted only 65 days.[3] In another example, the Atlas V has "a 35 percent part-count reduction compared to legacy Atlas IIAS."[4] Although the EELV systems are neither designed to nor able to meet the hope of "call up and launch" within a few days, the reduced processing time and reliability shown by the early EELV launches certainly enables an improved lift vehicle preparation process over heritage launch systems, and move

launch delivery capabilities closer to the goal of responsiveness.

Spacecraft Responsiveness

We have discussed the responsiveness of launch vehicles, but what about spacecraft responsiveness? Often, the most limiting element to responsive space is the satellite system. This is due to lengthy development, test, launch processing, and initial on-orbit checkout requirements. As an example, Milstar 4, the first of a new block of protected satellite communications spacecraft, underwent nearly four months of checkout after launch before being declared operational. This was two months faster than the planned six month checkout as AFSPC rushed to get the payload operational to support Operation Enduring Freedom. In addition to becoming more agile in the on-orbit checkout of spacecraft, we must continue to refine our satellite launch processing concepts to enable more agile launch operations.

Figure 2. Titan IV B-30 Launch—Cape Canaveral AFS, Florida.

Much has been said about evolving spacecraft toward a "ship and shoot" process, where payloads arrive at Cape Canaveral ready to launch, with limited to nearly no on-site assembly or testing required. In reality, there is a competitive tension between the desire to have a 'just-in-time' spacecraft flow at the launch site, consistent with booster processing for that vehicle, so that exposure to risk and expense is minimized, and a desire to have satellites 'in the barn' at the launch site, awaiting the short-notice call to replenish on-orbit capability. Based on the way satellites are designed today, the latter situation would inherently require repetitive processing and checkout at the launch site to ensure the satellite was ready for the mission, since spacecraft of today are not inherently designed to spend time in storage barns. There would have to be a paradigm shift in the satellite design criteria in order to support a "ship and shoot" posture. Experience has proven, however, that regardless of on-paper designs, launch-base integration and checkout is required and necessary for essentially all satellites built today. While it is not the intent to build an "extension of the factory," launch site experts do offer program managers and senior corporate and government leadership additional flexibility to ensure mission success, and, as experience has shown, they always take advantage of that flexibility. This is particularly true as we migrate from well-established legacy systems to one-of-a-kind payloads designed to perform unique missions.

Some concepts that may make spacecraft more responsive are a standardized spacecraft bus, modular payloads, and space-to-launch vehicle interfaces that can be rapidly reconfigured, but systems designed for a robust "responsive" posture will inherently add weight to the spacecraft—weight that provides no benefit to the satellite's prime mission on-orbit. Clearly managing the 'trade space' between satellite costs, reliability and complexity would have to be done differently to incorporate responsiveness as a priority. However, the approach of building simple, low-cost spacecraft for military purposes has begun with the advent of the tactical satellite (TACSAT) program, a program designed to challenge the current paradigm. The TACSAT demonstrations will prove to be extremely enlightening, as they will allow our current culture to evaluate new methods to develop operationally responsive satellites with high military value, agile tasking capability, quick delivery, and low cost.

Responsive Infrastructure and Support

Spacecraft and booster processing facilities and the workforce arrangement to make that processing happen are critical to responsive launch. For our heritage launch systems, time was not the driving factor. Instead, the complex and expensive payloads drove the focus to be 100 percent mission success. A launch site infrastructure plan and workforce was developed based upon serial, step-by-step assembly, test, monitor, and verification. This process involved hundreds of contractor technicians, engineers, and auditors and nearly an equal number of government and Aerospace personnel to oversee the contractor's actions. In addition, complex legacy launch vehicle systems came with equally complex ground support or handling equipment and the facilities that house them. For Titan, these complex facilities included the world's largest X-ray facility and a 13-story clean room for processing satellites on the launch pad. These unique facilities and the demands to maintain them now present themselves as inhibitors to responsiveness by their very nature, as they were designed for 100 percent mission success. Our current Department of Defense spacecraft processing facilities at the Eastern Range have supported the successful processing of a constellation of satellites that ensure America's space superiority and significantly enable military superiority and enhance national power. However, because these facilities were designed to meet specific program

Figure 3. First Atlas V Launch—Cape Canaveral AFS, Florida.

needs, they are limited in size, scope, and flexibility. Their age and design also make them costly to maintain and modernize. Further, the increased focus on tropical weather underscores their inability to withstand major hurricane strikes.

In order to meet the responsiveness envisioned for the future, we need to explore modular, secure, and storm-resistant processing facilities that can accommodate a wide variety of small to large spacecraft programs resident at Cape Canaveral, and the workforce necessary to execute a responsive launch concept of operations. To provide operationally responsive support at the launch site, the goal would be to identify pre-staged flight ready hardware, integrate the launch vehicle and satellite, mate the satellite to the launch vehicle, do an integrated systems check, and launch it. Ideally, as many steps as possible should be performed in parallel with a minimum of flight hardware movement. That requires a different workforce and facilities paradigm than are in place today for heritage programs.

However, it is worth noting that both EELV (Atlas V and Delta IV) processing concepts, although very different from each other, support the tenets of maximizing parallel processing and minimizing movement of flight hardware. The boosters and satellites are processed in parallel at separate facilities. Once ready they are brought together where the satellite is mated to the booster and an integrated systems check occurs. A few days later the integrated stack is ready for launch. While mission success is still the driving factor, the EELV processing timelines represent a significant improvement with end-state goals of less than two weeks, and the infrastructure and workforce were designed to support that goal. Not only have processing flows been improved, but EELV has also achieved a significant reduction in the number and complexity of facilities. In earlier days, facilities were designed to support a specific piece of the assembly and test process for each major component of the launch vehicle system. Now, with EELV, since the major launch vehicle components arrive at the launch site already assembled and checked out, the facilities are less specialized.

The EELV system, including launch vehicle systems, infrastructure, and processes, was designed for a new, commercially competitive environment. Relieved of some government requirements, the focus was on cost efficiency and commercial viability. Reduced processing timelines and increasing responsiveness and flexibility significantly cut projected costs and were key design drivers in facility development. Even though the motives that drove the paradigm shift for EELV could be considered 'profit-driven', the end effect for operationally responsive space will be based, in many ways, on EELV facility concepts.

A Responsive Range

Assuming the philosophical and programmatic challenges are overcome to produce an operationally responsive launch vehicle and spacecraft, the final key component necessary to the support of responsive spacecraft delivery to orbit is a responsive launch range. As General Klotz points out, "Our launch ranges do a superb job of supporting a myriad of users. But to meet responsive space needs, we'll have to expand coverage, quicken flight plan approval, and increase capability for higher flight rates."[5] Unlike launch and satellite vehicle responsiveness that are driven primarily by design, the responsiveness of the launch range is more a function of competing requirements, constraints, and policies that govern range operations at the Nation's primary launch-bases. These competing factors are the result of measures undertaken to address the greatest limitations on range operations: public safety and cost.

Figure 4. Eastern Range Radar.

The first challenge to creating a responsive launch range is public safety. The objectives of responsive launch constructs which seek to shorten flight plan approval can be understood in the context of the two extremes of the "responsiveness continuum."[6] As an example, for a commercial communications satellite launched from Cape Canaveral on an expendable launch vehicle, public safety takes a leading role. Strict constraints are imposed on launch execution. It is reasonable to assume that launches of the future, no matter how responsive, will face similar constraints. Being able to clearly articulate the operational requirements with respect to safety is key to establishing the necessary framework for the creation of a more responsive launch range.

The second fundamental limitation on range operations is cost. If each program had a dedicated suite of instrumentation and personnel, the responsiveness of the range would be exceptional. Of course, this is not realistic given the number of range users, the vast array of range requirements (driven by different payloads and trajectories), and the budgets established to pay for range opera-

Figure 5. A NAVSTAR GPS satellite mated to its 3rd stage motor in a processing facility at Cape Canaveral AFS.

tions and maintenance. This does not imply, however, that the launch ranges are not actively pursuing ways to improve efficiencies while maintaining an acceptable level of responsiveness to a variety of range customers. The range continues to address this challenge through improvements to range architecture, and the processes, facilities, and workforce that goes with it.

The architecture of the eastern range has existed in its current form for several decades: land-based tracking, data relay, and destruct systems. Just as recent military conflicts have illustrated the Nation's increasing dependency on space-based capabilities, the evolution of the launch ranges has also seen an increase in dependency on these platforms. For example, recent improvements in software tools have enhanced the range's ability to manage an increasingly complex range schedule; however, budget considerations have resulted in the cessation of 24-hour range scheduling support. The impact of a reduction in range availability can be mitigated through process improvements with respect to the current expectations of range customers (less need to schedule activity on the range), but any reduction may have an adverse effect on range responsiveness to short-notice requirements.

The advent of global positioning system (GPS) metric tracking and expanded use of NASA's Telemetry Data and Relay Satellite System are two examples of how exploitation of our current space-based technologies is reducing our dependence on expensive ground-based assets. For example, outfitting future launch vehicles with GPS tracking systems will enable both launch ranges to cut back on traditional radar and optical systems which are becoming very costly to maintain. The ability to reduce cost without reducing capability is absolutely essential to realizing the goals of an operationally responsive range, and overall, an agile launch delivery paradigm.

Summary

In spite of our history, we are on an evolutionary path toward more responsive space access. The EELV program has streamlined the overhead of readying boosters through a reduction of complexity, increase in reliability, and simplification of facilities. The TACSAT program will investigate the viability of responsive satellites with a strong emphasis on low cost and small, simple payload packaging. Likewise, the progress toward a capability such as GPS metric tracking can streamline the range architecture and supporting workforce while managing risks to the public. Elegant vehicle design, simpler processes for boosters and satellites, flexible spaceport facilities, reduced scheduling overhead for launch delivery—all of these evolutionary improvements are interrelated and must be synergized together as a total effort to gain the most leverage in the strategic goal of operationally responsive space access.

We have come a long way from the earliest days of space launch, but we have much yet to accomplish. Responsive launch vehicles, payloads, and ranges will not realize their potential without equally responsive acquisition and operations processes and organizations executing the mission from concept design through launch and on-orbit checkout. While getting to the desired end state will take time, it is important to realize we are making incremental progress every day. Through improved operations concepts, launch-base processes, and upkeep of critical space infrastructure, we as a Nation are moving our critical spacelift capabilities … toward responsive space access.

Notes:

[1] Lt Gen Frank G. Klotz, "Defining Responsive Space," speech, Responsive Space Conference, Los Angeles, CA, 25 April 2006.

[2] "US Space Transportation Policy," fact sheet, 6 January 2005, http://corport.hq.nasa.gov/launch_services/Space_Transportation_Policy.pdf#search=%22SpaceTransFactSheetJan2005%22 (accessed 25 September 2006).

[3] Titan IV B-39 was the next to last Titan IV mission from the Cape and the processing flow lasted 122 days. The last Cape Titan IV, the B-30 mission, was transferred from the West Coast and experienced delays due to hurricanes and payload problems estimated at approximately 120 of the 548 total days at the Cape. The most recent Atlas V launch, AV008, processing flow was 65 calendar days.

[4] Col R. K. Saxer, "Evolved Expendable Launch Vehicle System: The Next Step in Affordable Space Transportation," *PM Magazine*, March-April 2002, 2-15.

[5] Klotz, "Defining Responsive Space."

[6] Mr. Kelvin Coleman and Lt Col Tim Brown, "Commercial Range User Requirements Process," briefing, slide 7, 23 May 2006, http://ast.faa.gov/ppt/LOSWG/Coleman.ppt (accessed 25 September 2006). Responsive Launch Traffic Control seeks to shorten flight plan approval timelines from months to hours.

Brig Gen Susan J. Helms (BS, Aeronautical Engineering, US Air Force Academy, Colorado; MS, Aeronautics/Astronautics, Stanford University, California) is commander, 45th Space Wing, Director, Eastern Range, Patrick AFB, Florida, and Deputy Department of Defense Manager for Manned Space Flight Support to NASA.

As the 45th Space Wing commander, she is responsible for the processing and launch of US government and commercial satellites from Cape Canaveral AFS, Florida. She is the final approval authority for all launches on the Eastern Range, a 15-million-square-mile area that includes a network of radar, telemetry tracking, and telecommunication hardware operating at sites up the East Coast and in the Atlantic Ocean including detachments at Antigua Air Station and Ascension Island. The range supports an average of 20 launches per year aboard Delta and Atlas Evolved Expendable Launch Vehicles, assuring access to space for America. General Helms also manages wing launch and range infrastructure supporting space launch and missile test operations.

General Helms was commissioned from the US Air Force Academy in 1980. She has served as an F-15 and F-16 weapons separation engineer, a flight test engineer and project officer on the CF-18 aircraft as a US Air Force Exchange Officer to the Canadian Aerospace Engineering Test Establishment, and an astronaut. General Helms is a graduate of the Air Force Test Pilot School, Flight Test Engineer Course, Edwards AFB, California, and as a flight test engineer, she has flown in 30 types of US and Canadian military aircraft. Selected by NASA in January 1990, General Helms became an astronaut in July 1991. She flew on STS-54 (1993), STS-64 (1994), STS-78 (1996), STS-101 (2000) and served aboard the International Space Station as a member of the Expedition-2 crew (2001). A veteran of five space flights, General Helms has logged 211 days in space, including a spacewalk of eight hours and 56 minutes, a world record.

The Power to Explore – America's Next-Generation Fleet of Launch Vehicles

Mr. Robert C. Armstrong, Jr.
Deputy Manager for Integration,
NASA Exploration Launch Projects Office

In the not-too-distant future, the first human will land on Mars. This pioneer will be equipped with information from numerous scientific spacecraft orbiting the red planet, as well as a variety of successful surface rovers that have given researchers tantalizing insight into Earth's cosmic neighbor. This pivotal event will shape the landscape not only of space pre-eminence, but also of leadership on our home planet. To begin that far-reaching journey, near-term lunar exploration will prepare astronauts to travel to Mars, while yielding new knowledge about Earth and its largest satellite—the moon.

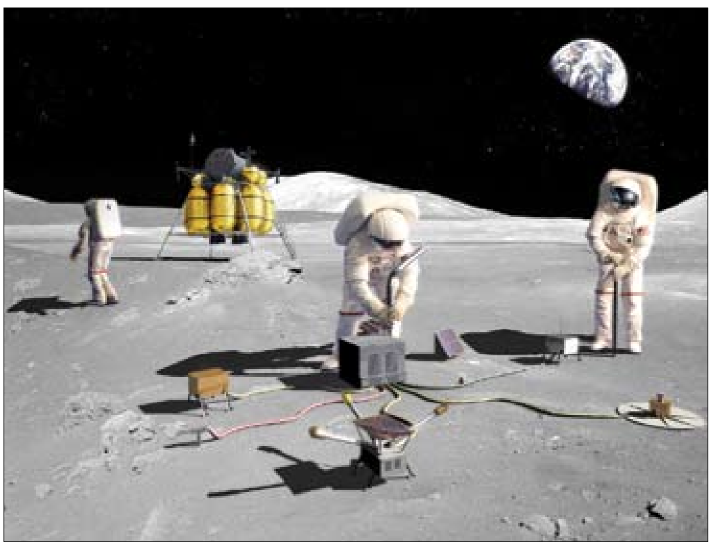


Figure 1. America is returning to the Moon to prepare for longer journeys to Mars. (NASA artist's concept)

As it prepares to retire the venerable Space Shuttle, National Aeronautics and Space Administration (NASA) and its partners are engaged in designing and developing the Ares I launch vehicle, which will loft the Orion crew exploration vehicle into orbit early next decade, and the Ares V heavy-lift launch vehicle, which will propel the lunar surface access module into space late next decade, in preparation for America's return to the moon. Unlike the Apollo missions in the late 1960s and early 1970s, this new wave of exploration will give astronauts the opportunity to live off the planet for long periods, establishing a permanent base from which to trek across a vast amount of uncharted territory and discover important resources.

While astronauts are logging time living and working on the International Space Station and on the moon, engineers will continue to evolve these new space transportation architectures into configurations that are suitable for the much longer trips to Mars—on the order of years, rather than days, weeks, or months. This initiative will position the United States to master space, much as earlier pioneers conquered the land and seas in the 18th and 19th centuries, and the air and low Earth orbit in the 20th century. Setting a course for the unknown always carries with it great risk, but the resulting benefits have consistently proven the worth of such daring endeavors.

Figure 2. The Ares I launch vehicle will deliver the Orion crew capsule to orbit. The Launch Abort system on top of the capsule will improve crew safety and survival in the event of a launch emergency during ascent. (NASA artist's concept)

The Exploration Launch Projects Office at NASA's Marshall Space Flight Center, Huntsville, Alabama, manages the Ares I and Ares V vehicle developments for the Constellation Program Office, located at NASA's Johnson Space Center, and for the Exploration Mission Systems Directorate at NASA Headquarters in Washington, DC. Several prime contractors have

Figure 3. The Ares V Earth departure stage will deliver heavy cargo to orbit. (NASA artist's concept)

been brought on board and other acquisitions are forthcoming.

To deliver the best value for the investment within the target timelines, this government and industry team is drawing upon past equipment and lessons learned and transitioning those traditions into modern systems that are safe, reliable, and affordable. With an eye on the distant horizon, the team is obliged to fulfill these goals and objectives to promote sustainable exploration across the decades ahead.

Rocket Science at Its Finest

Across the country, rocket scientists, business planners, technicians, and operations experts are designing the next generation of launch vehicles and spacecraft that will assure United States access to space. The Ares I will deliver the Orion crew capsule to orbit by 2014. In the 2020 timeframe, the Ares V's Earth departure stage will carry the lunar surface access module to orbit, where Orion will dock with it for the trip to the moon. Once in lunar orbit, the crewmembers will transfer to the lunar lander, which will transport them to and from the moon's surface. After completing their mission on the moon, the astronauts will board Orion and head home to a landing on Earth.

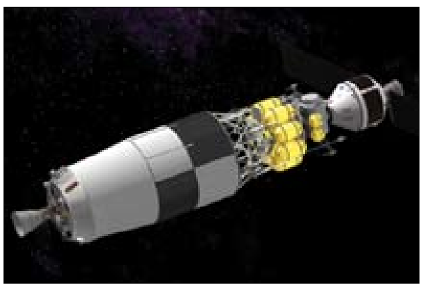


Figure 4. The Orion capsule will dock with the lunar surface access module and the Earth departure stage, which will propel the mated combination into lunar orbit. (NASA artist's concept)

The Ares I will be launched upon a Space Shuttle-derived reusable solid rocket booster first stage, and will reach orbit using its upper stage, which will be powered by an Apollo Saturn-derived J-2X engine. The Ares V will use two solid rocket boosters similar to the Ares I first stage and a core propulsion stage consisting of a Saturn-class tank delivering fuel to a

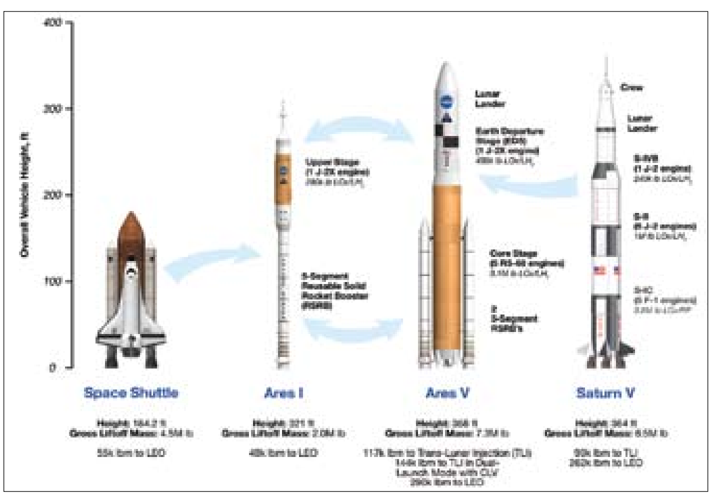


Figure 5. The Ares I and Ares V propulsion elements are derived from past and present proven systems. The arrows show how the two vehicles share common hardware, to reduce development and operations costs and risks. (Vehicle drawings are shown to scale.)

cluster of five RS-68 engines, which were originally developed for the Department of Defense's Evolved Expendable Launch Vehicle Program. The Earth departure stage's J-2X engine, which is the same as that used for the Ares I upper stage engine, will perform the trans-lunar injection burn. This hardware evolution and commonality is expected to reduce technical, schedule, and cost uncertainties in the high-risk business of space transportation.

Test as You Fly

While the Ares V planning is still in the early stages, the first test flight of the Ares I will take place in 2009. In 2006, during the first of several major milestones, the Exploration Launch Projects Office will conduct the system requirements review to examine the functional and performance requirements defined for the Ares I and ensure that the requirements and the selected concept will satisfy the mission. NASA performs systems engineering trade studies and conducts well-defined reviews to bring together the wide range of engineering disciplines needed to develop an efficient, effective, and integrated space transportation system. Applying industry standards and best practices, these engineering and business experts will investigate the subsystems, ranging from avionics to thermal protection, to determine the best way of delivering an integrated system that can deliver the power to explore the moon, Mars, and beyond.

As part of the philosophy for successively refining the vehicle concept, a variety of high-tech tools are used to inform decision-making—from relatively straightforward algorithms and statistical formulas, to complex virtual reality environments where the vehicle can be flown in cyberspace and operators can interact with the two-dimensional system while having the sense of three-dimensional space. This research will culminate in flight-testing, which provides real-world data on which to base critical design and operations decisions.

Engineers currently are performing a series of analyses to determine the optimum design solutions for the requirements demanded of the system, such as launch availability under a variety of weather conditions and turnaround time to prepare

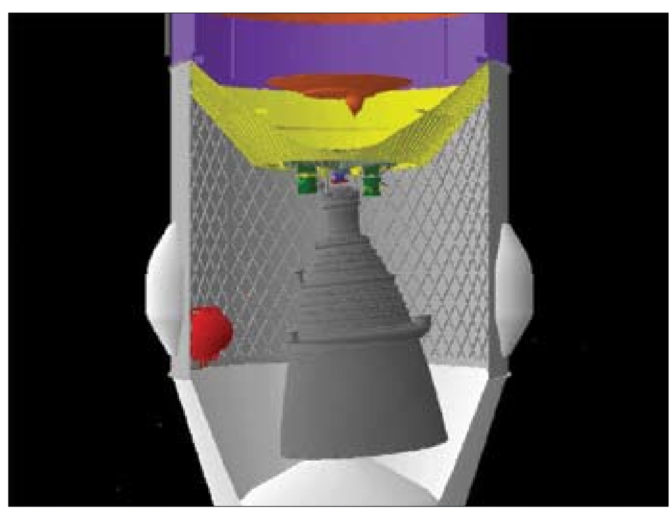


Figure 6. Checking the clearance of a virtual J-2X engine bell within the upper stage structure.

the system for flight. Using data from subscale models "flown" in wind tunnels and from hardware testing such as shuttle solid rocket booster firings during tests and actual flight, rocket engineers marshal a portfolio of design assets. Added to this is component testing, such as that already in progress for the J-2X engine. Beginning in 2009, a series of flight tests will be conducted, first with mockup hardware at suborbital altitudes, and then evolving to full-scale hardware performing orbital missions. This incremental approach to testing will form a well-laid foundation upon which to field America's new fleet of rockets.

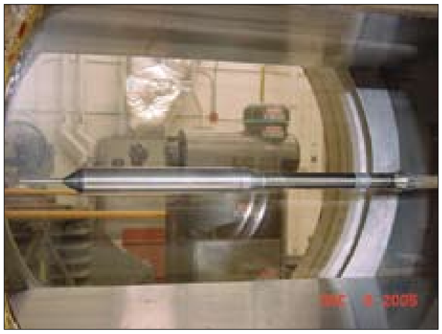


Figure 7. Wind tunnel models provide a vast amount of early data to the aerodynamic database being created by the Ares team.

Leveraging Collaboration and Resources

This design and development work is progressing at NASA centers and aerospace companies across the Nation. Recently, a memorandum of agreement was signed between NASA and the US Air Force Space Command to upgrade the RS-68 engine with performance modifications that will benefit both organizations. Synergies such as this will help reduce technical, cost, and schedule risks in this complex business.

Costly invention and reinvention are prevented by drawing on the best workforce and facilities NASA has to offer. For example, the massive Michoud Assembly Facility in New Orleans, Louisiana will be retrofitted for future Ares manufacturing. This is the same facility that made the Saturn V and now produces the Space Shuttle tanks. Likewise, test stands, launch pads, and other ground and mission operations centers across the Nation will be modernized for this 21st century fleet and its payloads. Processing concepts and mission scenarios are being scrubbed to reduce operations costs, including increasing automation and accessibility, while reducing the touch labor needed to process and fly a space vehicle.

Figure 8. Astronauts will one day explore Mars, the planet in our solar system most like Earth. (NASA artist's concept)

How High are the Stakes?

The most powerful nations on Earth have the ability to launch astronauts into space. National strength also derives from collaborative scientific and exploration endeavors that offer unique opportunities for international partnership on a grand scale. Yet, without a doubt, the country that places the first footprint on Mars will be the one that also is predominant on our home planet.

Although NASA's budget comprises less than one percent of Federal spending, delivering this new capability has enormous implications for economic expansion and national security. The Ares I and Ares V launch vehicles are on track to deliver America's payloads to space, contributing the power to pioneer new routes to undiscovered territories and the resources they offer those bold enough to strike out on the next leg of the journey.

Robert C. Armstrong, Jr. (BS, Virginia Polytechnic Institute and State University) is Deputy Manager for Integration in the Exploration Launch Projects Office located at NASA's Marshall Space Flight Center, where he is responsible for strategic planning and operational execution.

Mr. Armstrong's areas of expertise include engineering and business, internal and external communications, and interrelated systems and processes designed to enhance mission success for one of NASA's highest priority projects, which is developing the next generation of safe, reliable, and cost-effective space transportation systems for the human exploration of the Moon, Mars, and beyond.

Previously, Mr. Armstrong was a Project Manager for the Orbital Space Plane Program and the Space Launch Initiative. He also served in the Pathfinder Program, the Space Station Program Office, and the Chief Engineer's Office. Prior to that, he was with the Program Development Office, working on various space architecture concept activities. He began his NASA career in 1981 as a Project Engineer in the Systems Dynamics Laboratory.

Prior to joining NASA, Mr. Armstrong was a Project Engineer at the Arnold Engineering Development Center (AEDC) in Tullahoma, Tennessee, where he conducted hypervelocity tests at various AEDC facilities, including the infamous "chicken gun" which was used to verify that military aircraft windshields could withstand bird impacts.

Increasing the Solvency of Spacepower

Maj John Wagner, USAF
Operations Officer
45th Launch Support Squadron

The key question that you should be asking is: Can the Air Force get its space programs back on the right path?
- Senator Wayne Allard (R-Colorado)

Military spacepower has historically proven to be a solid investment for the United States. With operating costs a third or less of developmental costs, and spacecraft lifetimes that exceed 10 years of continuous operation, space capabilities provided to armed forces and government agencies have bolstered each of the US national instruments of power and helped secure America's place as the leader on the world stage. In some cases, such as the enormous growth of global positioning system (GPS) applications beyond military position, navigation, and timing, American spacecraft have revolutionized worldwide transportation and commerce—increasing US credibility and prestige worldwide through technological leadership. With weather prediction and forecasting, advanced satellite communication, missile launch and impact warning, precise position, navigation and timing, and multiple methods of intelligence, surveillance and reconnaissance, US military space programs have proven essential to national security. Further, military space has enabled the transformation of all services, branches, and specialties into more integrated, more lethal and ultimately *more effective* forces with a smaller number of personnel.[1]

However, recent space-related headlines and official statements focus on significant problems with space acquisition—significant cost overruns, technical problems, and delays in fielding spacecraft and launch vehicle systems. Military analyst Loren Thompson commented that "Every one of the next-generation constellations being developed has encountered unanticipated cost growth, schedule slippage, and technical difficulties. The problems are so pervasive that they raise doubts about whether government and industry can successfully execute military plans for space."[2] Thompson is not alone in this view. Lt Gen Larry J. Dodgen, the commander of the US Army Space and Missile Defense Command, stated that the Army's Future Combat Systems are "dependent upon things that will be there in space … [and] I have severe doubts whether or not such capabilities will be available as planned."[3] A more scathing critique, indicating the depth of the problem, came from Senator Wayne Allard, Chairman of the US Senate's Space Power Caucus and Appropriations Committee member. During a speech to the National Defense Industrial Association, Senator Allard said, "Over the last decade, we have done everything possible to sabotage our space supremacy. And, we have done this in every area of government at every possible turn. Our warfighters, program managers, contractors, and yes, even Congress [is] responsible, and all are guilty of ignoring the warning signs."[4]

These criticisms come at a critical juncture for military space. Heritage spacecraft, designed against Cold War threats, have performed well throughout their design lifetimes, but their time on-orbit is running out (Table 1). The Department of Defense (DoD), with the Air Force as Executive Agent for Space, is now in the unenviable position of having to modernize *all* of its current on-orbit systems. Every spacecraft constellation is in transition. Delays and cost overruns are no longer a nuisance—they threaten the recapitalization of existing, and development of future, military space capabilities and the expansion of these capabilities to ensure the space superiority of the United States. For example, when the DoD awarded the system prime contract to Lockheed Martin in 1996, space-based infrared system–high (SBIRS–high) was expected to cost about $2 billion and launch the first spacecraft by 2002. However, its first launch has (currently) slipped six years to 2008, and program costs have ballooned to $10.64 billion in current fiscal year dollars, triggering Nunn-McCurdy congressional reviews in December 2001, June 2004 and July 2005.[5] The Air Force will spend $9.8 billion on space programs in fiscal 2007, *19 percent* of Air Force modernization spending.[6]

Spacecraft	Launch Date*	Age**	Design Life (years)	Average Age**
MILSTAR-6	8-Apr-03	3.15	10	7.14
MILSTAR-1	7-Feb-94	12.32		
GPS IIR-14 (M)	26-Sep-05	0.68	10	8.43
GPS IIA-15***	9-Sep-92	13.73		
DSP-22	14-Feb-04	2.3	3 (goal 5)	8.48
DSP-14	14-Jun-89	16.98		
DMSP-16	18-Oct-03	2.62	3	8.24
DMSP-12	24-Mar-95	11.76		
UFO-11	18-Dec-03	2.45	10	10.13
UFO-1	25-Mar-93	13.19		
DSCS IIIB-06	29-Aug-03	2.76	10	8.53
DSCS IIIB-22	2-Jul-92	13.92		

Table 1. Spacecraft Age: Oldest and Newest Operational Spacecraft in Constellations.
** Launch dates in ZULU, according to the AFSPC Launch Information Support Network (LISN) database.*
*** As of 1 June 2006*
**** Note: This is the 28th spacecraft from the latest launch, comprising a full constellation with spares. A few older spacecraft remain operational, but age calculations are limited to the 28 most recently launched spacecraft.*

Exacerbating the problem is the fact that many of the cost overruns, delays and corresponding congressional funding cuts to recapitalize spacecraft have occurred during *rising* military budgets. This is not a guaranteed trend. Recent years have significantly eroded discretionary spending. Since 2001, the US has spent billions of dollars on fighting two wars and insurgency operations, homeland security, gulf coast hurricane recovery, and a Medicare drug benefit that in itself will cost an estimated $797 billion over 10 years.[7] As a result, Deputy Defense Secretary Gordon England directed the military services in a 2005 memo to cut some $32 billion in projected spending through 2011.[8] "We are at a critical juncture," Senate Budget Committee Chairman Judd Gregg told Pentagon officials at a hearing in March 2006. "Just as we strongly support the war on terrorism, we must also recognize that there is no such thing as an unlimited budget. Difficult choices must be made."[9]

Strategy is about making difficult choices. The best strategies not only effectively achieve objectives, they do so *efficiently* as well—at the lowest cost of any option.[10] In war, this obviously means avoiding pyrrhic victories and ensuring objectives are reached at an acceptable cost in personnel and material. Throughout war and peace, acceptable force structures must be developed that anticipate future victory at an acceptable cost, in order to ensure the United States maintains a continuing national advantage. The status quo approach to space acquisition will result in significant cost growth over the next five years until recapitalization peaks around 2011 (figure 1).

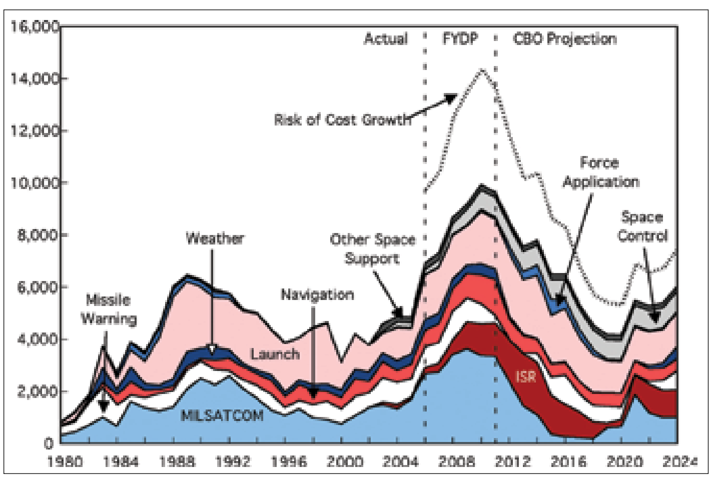


Figure 1. Overall Investment in Unclassified Space Systems ($ millions).

The Air Force is under further fiscal pressure to modernize its *air* fleet due to ongoing structural issues, corrosion, wiring problems, and other component failures.[11] Tradeoffs in needed air and airbase force structure cannot be put off indefinitely. Though Secretary of Defense Donald H. Rumsfeld ratified space as a separate and distinct military mission area, the Air Force continues to fund what are, in effect, two major military mission areas—air and space—with an annual budget share intended for only one. Although all military services and most US government agencies benefit from space-derived products and services, the Air Force provides nearly all military space funding, providing other services with essentially a free ride.[12]

Meanwhile, demands for space support and space force enhancement by all services have grown significantly. Despite the need to recapitalize both air *and* space forces, the historical trend (figure 2) illustrates DoD's unwillingness to significantly alter service funding percentages since 1970. Therefore, increased dependency on on-orbit spacecraft aging beyond their design lives (table 1), coupled with increased difficulty to replace these spacecraft, leads to increased near-term US spacepower vulnerabilities.

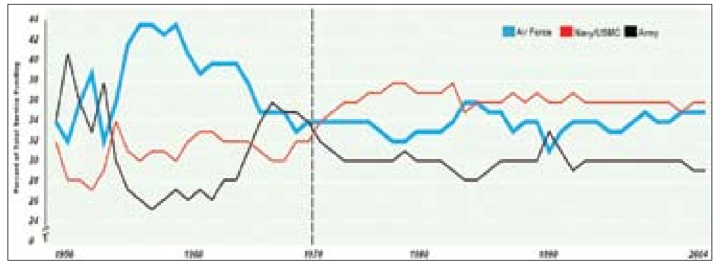


Figure 2. Historical Service Funding Percentages.

The US General Accounting Office (GAO) attributed the significant space acquisition cost increases and schedule delays to two primary factors: first, the DoD seldom matches resources to requirements at the start of an acquisition program, and second, the DoD funds programs continually without consistently establishing priorities.[13] These two factors explain the root problem—too many space systems compete for limited funds, with competing contractors submitting proposals that reflect only minimum program content and are simply priced to win the contract. Basing its decisions on these unrealistically low initial cost estimates, the DoD starts more programs than it can afford in the long run.[14] This practice had the cascading effect of promoting negative behavior to compete for funds, creating unanticipated and disruptive funding shifts, *increasing* technological challenges, and stretching out schedules in order to accommodate the whole portfolio of space programs (as shown in figure 3).[15]

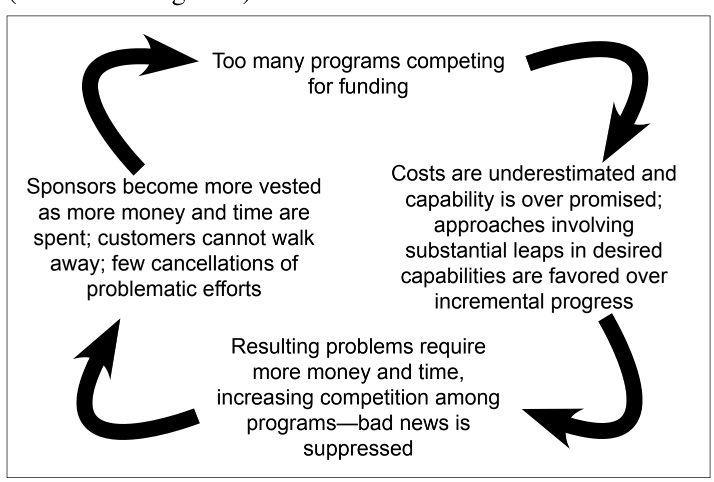


Figure 3. Pressures Resulting from Too Many Space Programs.

The Spacepower Paradigm Shift

If spacepower is increasingly unaffordable, but unavoidable, how can the solvency of spacepower be increased? The key lies in understanding the current paradigm and examining if it is the

proper approach for the future of military space. Paradigms involve a set of assumptions, concepts, values, and practices that constitutes a way of viewing reality for the community that shares them. When Thomas S. Kuhn popularized this term by publishing *The Structure of Scientific Revolutions,* he centered his analysis on intellectual disciplines. The rules of *normal science* help bound a specific problem and focus resources. However, Kuhn states that science is often "riddled by dogma" and a shift in professional commitments to shared assumptions takes place when an anomaly "subverts the existing tradition of scientific practice."[16] The "existing tradition" of spacepower acquisition is characterized by a need for large spacecraft-centric force enhancement systems and associated high opportunity costs due to limited options, high costs of failure, with the need to reinvent entire constellations every 10 to 15 years to keep pace with changing technology. This leads to the pursuit of *bleeding edge* technology and integrating it on only a handful (or less) of spacecraft with no way to test and demonstrate either the technology or the system in its operational environment before launch of the production spacecraft.

Test Programs

Problem solving is a normal part of any development process, and testing is a proven tool for discovering problems. The GAO has long been advocating more robust DoD test programs. Despite the GAO push, numerous DoD weapon programs still suffer from persistent problems associated with late or incomplete testing.[17] With specific attention to spacecraft, the GAO lauded an attempt by the Missile Defense Agency (MDA) to fly demonstration spacecraft before developing and producing them in larger numbers. The GAO found this to be a best practice used by successful commercial programs, where components and subsystems demonstrate system functionality before investing a greater amount of procurement funds.[18]

However, space systems do not benefit from a system development and demonstration phase afforded to other DoD acquisition programs (figure 4), due to an inability to demonstrate and evaluate advanced technologies among different types of spacecraft in their operational environment. Rather than a *fly-off*, the down-select between spacecraft contractors usually occurs at some point during the design phase by having some sort of a *design-off*. Further, there is no extensive flight test period after launch. Program managers thus expect spacecraft to be operationally flawless and operate maintenance free for 10 to 15 years in a *launch-and-leave* paradigm—every booster must successfully launch an operational spacecraft, including the very first model in a series. This equates to designing the next advanced aircraft on paper, choosing the manufacturer based on that design, then building the first model and integrating it into an operational squadron for its first flight. This stands in stark contrast to the US Air Force aircraft acquisition model.

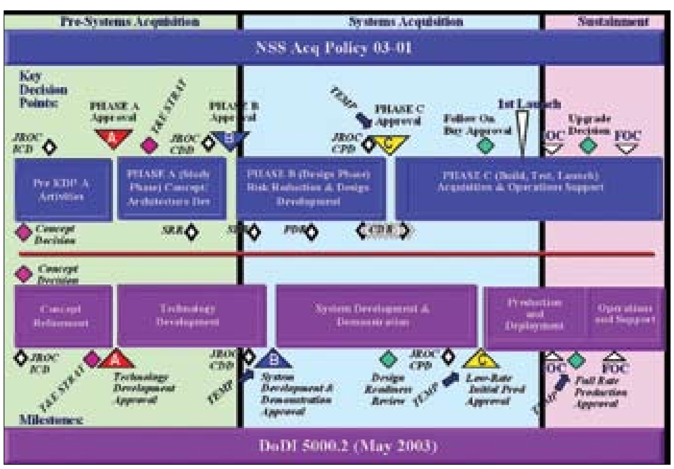


Figure 4. Space Acquisition Policy versus DoD Acquisition Policy.

Every aircraft, before it was allowed to enter the Air Force inventory—and a great many that failed to do so—was put through its paces at the Air Force Flight Test Center at Edwards AFB, California. The turbojet revolution, the aerospace revolution, the systems revolution, and now the unmanned aircraft revolution have overcome seemingly insurmountable obstacles through a combination of technical aptitude, daring ingenuity, and skillful management.[19] The same rigorous *test before production* methodology that has been an integral part of advanced aircraft development for over 60 years could be applied to spacecraft and spacecraft systems. In line with this paradigm shift, the Air Force should establish the Air Force Spaceflight Test Center (AFSTC), utilizing highly qualified board-selected military and civilian personnel with advanced education in space-centric disciplines such as astronautics, materials science, physics, and electrical engineering. This active duty Air Force advanced skill set is essential to test and evaluate emergent spacecraft and launch vehicle performance encompassing critical communication, sensor, and orbital maneuvering parameters, along with exploring optimal ground station capabilities and configurations. In doing so, emerging technologies can mature and critical capabilities can be demonstrated. In other words, the AFSTC would enable the DoD to work out the bugs in spacecraft and launch vehicle design through a definite and determined process focused on the difficult technical problems presented by cutting edge space systems. This should be in a separate stream from the typical program office focus on large program production and launch issues, which typically include production schedules, launch vehicle integration, and contract execution.

The AFSTC concept offers an additional, but significant, benefit. While an experimental X-vehicle or a prototype Y-vehicle aircraft is of negligible (and perhaps even negative) value in a future conflict, promising prototype spacecraft could be employed quickly and easily to augment existing constellations.[20] The performance of the Midcourse Sensor Experiment (MSX) spacecraft underscores the long-lasting utility of experimental spacecraft to operational space capabilities. MSX launched in 1996 as a spacecraft technology demonstrator to identify and track ballistic missiles during their midcourse flight phase. After proving successful in that role for the Ballistic Missile Defense Organization (now MDA), MSX was transferred to AFSPC in 1998, where it continues to function as the first and only space surveillance spacecraft—providing operational space surveillance observations vital to the AFSPC and US Strategic Com-

mand (USSTRATCOM) missions of space control.[21]

The shift towards the AFSTC will solve pressing problems that long have evaded solutions. GAO reports have stated for some time that weapon system acquisition programs have taken on technology development that should occur in a science and technology environment. Such acquisition programs have been unable to align customer expectations with resources and thus minimize problems that could hurt the program in its design and production phases. In fact, many of the space programs the GAO reviewed over the past several decades have incurred unanticipated cost and schedule increases because they began without knowing whether technologies could work as intended and invariably found themselves addressing more costly and time-consuming technical problems.[22]

Fortunately, many of the pieces of the AFSTC are already in place. Kirtland AFB, New Mexico is uniquely positioned to be the AFSTC. Detachment 12 of the Space and Missile Systems Center, recently renamed the Space Development and Test Wing (SDTW), is located in close proximity to the Air Force Research Laboratory's Space Vehicles Directorate (AFRL/VS) for ready access to the DoD's premier spacecraft science and technology research center. The SDTW currently has a small to medium-lift rocket capability, a spacecraft production capability, and a research and development spacecraft ground station capability—all encompassed in a responsive contract known as indefinite delivery indefinite quantity (IDIQ). IDIQ provides a true responsive space option, as responsive spacepower requires responsive contracting. IDIQ bypasses the lengthy source selection process, and space-certified hardware can be ordered as needed.[23] The SDTW's ability to rapidly execute contracts is in place for each of their services: An IDIQ for ten years for Minotaur launch vehicle services, a rapid operation support contract in place for spacecraft checkout and on-orbit operations, a low-cost IDIQ launcher contract for either the SpaceX Falcon or an Orbital Sciences Corporation upgraded Pegasus launch vehicle called the Raptor, and a recently (March 2006) awarded standard interface vehicle contract that builds small spacecraft with a non-proprietary standardized payload-to-experiment interface.[24]

Each of SDTW's major capabilities—the Rocket Systems Launch Program (RSLP), Space Test Program (STP) and Research, Development, Test and Evaluation Space and Missile Operations (RDSMO)—has a long history that helped shape the US military space program. RSLP currently maintains an inventory of 60 Minotaur IV boosters—three stages of stored Peacekeeper missile motors and a fourth stage Pegasus—able to launch 2,500 lbs. into a 500 km altitude sun-synchronous orbit for a $21 million recurring cost. RSLP also maintains an inventory of 170 Minotaur I launch vehicles based on the Minuteman missile first two stages that can send up to a 750 lbs. payload into a 400-nautical mile altitude, sun-synchronous orbit at $20 million a copy (figure 5).[25] Regarding spacecraft production, STP's current missions include serving as the primary provider of mission design, spacecraft acquisition, integration, launch, and on-orbit operations for DoD's most innovative space experiments.[26] Notable recent missions include the XSS-10 and XSS-11 spacecraft—proof of concept vehicles for highly maneuverable small satellites. As for the ground segment, RDSMO has the capability to rapidly reconfigure and emulate a wide variety of satellite ground stations. Further, it has the capacity to run multiple on-orbit operations simultaneously at different classifications. This capability could be utilized to test and evaluate the performance of two experimental spacecraft vehicles—a true spacecraft *fly-off*—to select a winning design for a production run while protecting proprietary operational data.

Courtesy of Orbital Sciences Corporation

Figure 5. Minotaur IV and Minotaur I.

Integrating and expanding the SDTW's current capabilities into the AFSTC offers an ability to demonstrate space science and technology investments, enhance institutional and individual learning curves, and provide increased and low cost access to space for critical research and development payloads. As of 2004, less than 25 percent of DoD's space research and development payloads made it into orbit, and this number included a heavy reliance on the Space Shuttle.[27] The investment in the AFSTC can counter this trend with an enormous potential payoff in realizing the long-standing goal of responsive spacecraft and launch systems. An important additional aspect of the AFSTC is the institutional and individual learning that will take place. As an institution, the Air Force will learn alternative methods and processes to conduct space operations that are not apparent through the current approach to fielding space constellations. The opportunity to manage smaller-scale experimental spacecraft provides hands on experience from start to finish, offering space professionals the opportunity to better prepare for managing larger, more complex space system acquisitions and operations.[28] Additionally, the cost and consequence of failure is reduced, as an experimental spacecraft is not the first in a limited number, high-tech/high cost production run. To reach the potential of this concept, however, the US Air Force must examine new approaches for spacecraft design.

Baselined Spacecraft Bus: Plug and Play

As much as 70 percent of modern spacecraft systems are

similar or, in some cases, identical—including power generation, attitude control, thermal control systems, communications systems, state of health sensors, mechanical structures, and onboard computer systems. Much like a public transit bus that gives various people a ride to where they need to go, these components comprise the spacecraft bus that transports and supports a variety of payload systems as they conduct their given mission(s) in the space environment. In contrast to the current approach to spacecraft acquisition, where a given program office is responsible for the acquisition of a spacecraft constellation, a spacecraft system program office could be established with the responsibility for developing and procuring "the basic satellite 'shell' for the 'production' programs."[29] This concept, according to Douglas Lee, would free current spacecraft program offices to focus on their specific core mission components, such as communications, intelligence and early warning. Further, an existing spacecraft bus and a structured design process would define *plug-and-play* for spacecraft much as a computer user can exchange or upgrade components. As payload sensor or technology emerges, the program office can target technological advances and integrate them onto spacecraft as they mature, even late in the test or production cycle.[30]

A Spacecraft Bus Program Office (SBPO) with modular and standard interface specifications could present a menu of options from which payload program managers could pick and choose—in effect selecting a specific spacecraft bus version or model. If new missions require increased maneuverability, counterspace options or power requirements, for example, it becomes the SBPO's problem. If the SPBO cannot satisfy the new requirements with off-the-shelf components, the SBPO designs the new component while the payload program manager remains focused on producing the specific payload. Once the new component becomes available, the SPBO includes it in its portfolio of options available to all other spacecraft payload programs. Further, this concept reduces the technology paradox as the spacecraft system can be modified with updated technology *during* its design and production. As technology matures, a program office can integrate upgrades onto the spacecraft prior to launch rather than restarting production lines for a new spacecraft system or holding launch and on-orbit operations in abeyance while waiting for a technological leap required to field a system.

To get to that point, however, a common set of definitions and standards, including interface specifications, power limitations, and weight and volume constraints for modular and scalable satellite buses is essential. Common standards are critical to achieving the agility and flexibility demanded by an operationally responsive space model, and "must be a part of our future plans and will allow us to increase the utility margin of smaller satellites."[31] Industry provides an example of a common-bus approach for cost utility on select geosynchronous spacecraft. From Zhongwei-1 (ChinaStar-1), launched in 1998, to the bus for both SBIRS-high and Advanced Extremely High Frequency Communication (AEHF), Lockheed Martin evolved their A2100 spacecraft series to a modular design that features a reduction in parts, simplified construction, increased on-orbit reliability, and reduced weight and cost. Lockheed Martin directs much of their research and development toward increasing the power available on the A2100 bus, which is currently capable of generating 15 kW in its standard configuration. Company engineers claim that they can deliver a satellite using the A2100 bus in 18 months after receipt of the order.[32] However, the militarized version (A2100M) has yet to launch, and AEHF and SBIRS-high continue to exceed original cost estimates. We have yet to develop a standard bus with plug-and-play payload components, and it is a critical step towards responsive spacepower. The next step is developing responsive launch vehicles, infrastructure, and organizations.

Responsive Space Launch

The Air Force has touted the need for responsive space launch for over 20 years. Since the loss of the Space Shuttle Challenger in 1986, the DoD spent over $4.4 billion on affordable, responsive space launch (National Aerospace Plane, Advanced Launch System, Space Operations Vehicle, and others)—with little to show for it.[33] The DoD has further touted the need for small launch vehicles that could be launched in days, if not hours, and lower costs that would better match the small budgets of experiments and quickly launch under 1,000 lbs. to orbit. A 2003 Air Force study determined that EELV would not be able to satisfy these requirements. Building low-cost launch vehicles could create opportunities for innovative companies to compete for Air Force contracts and broaden the space industrial base. However, industry representatives told Air Force officials they receive mixed signals from the government regarding its commitment to these efforts—much talk but little funding.[34]

True responsive space requires an organizational shift away from program offices and new contractor starts. To facilitate the appropriate changes, the Air Force should establish responsive space launch as a *blue-suit* Air Force mission, formally recognizing that assured and timely access to orbit is the nexus between space acquisition and operations. Without successful launch, there are no space operations—and a significant amount of national treasure in time and resources developing the spacecraft, booster and associated mission support infrastructure are wasted. The infrastructure is currently in place for responsive space launch organization at both the eastern and western launch ranges. Space Launch Complex-8 at Vandenberg AFB, California (60-120 degree inclination) and Launch Complex-46 at Cape Canaveral AFS, Florida (28.5 to 40 degree inclination) currently support, and other government pads could be built to support, Minotaur or similar launch vehicles that rely on heritage Minuteman and Peacekeeper missile stages.[35] These stages operate on established Air Force technical orders that could be modified with minimal effort to meet Minotaur or other modifications to the basic booster stages and associated electronics that result in an operational launch vehicle. Both bases have extensive missile storage capacities, in-place technical advisors (such as Aerospace Corporation), experienced contractors, technicians, and Air Force quality advisors, along with world-class payload clean-room facilities, large aircraft runway

facilities, range safety representatives, and a significant launch and range support infrastructure. This infrastructure can support a safe storage of a number of launch vehicles and payloads for a true launch on need capability.

As then Brig Gen Robert C. Hinson stated, "We have blue-suit maintenance people who never touch a wrench, operations people who never launch a booster …"[36] While their quality advisor role has been invaluable in mission assurance—monitoring and correcting contractor tasks for large boosters, these personnel could be effective in operationalizing small boosters based on familiar former intercontinental ballistic missile (ICBM) platforms. Current missile maintenance training is in place for these systems and active-duty enlisted maintenance personnel (2M0XX Air Force Specialty Codes) are assigned to these bases. Further, a training pipeline is already in-place to generate more 2M0XX's as needed, or preferably, add personnel with proven experience from the northern tier ICBM bases. Missile maintenance technicians and officers would work with a small cadre of engineering and space operations officers with the mission to continuously train and exercise their mission to integrate, test and launch a standard *plug-and-play* booster and spacecraft within days of a launch order from USSTRATCOM. As an AFSTC Detachment, this team would prepare and launch experimental spacecraft the same way they would execute their wartime tasking. Routine experimental AFSTC launches would thus validate their training on a periodic basis.

To ensure maximum flexibility, the Air Force must consider both air and ground launched responsive space options. The current air launched Pegasus XL has the capability to launch a 976 lbs. payload into a low Earth orbit (LEO) for $13.5 million using an L-1011 aircraft launch platform.[37] The RSLP's current $100 million IDIQ contract for modified versions of the Pegasus on either the Raptor 1 (a winged, three-stage solid rocket vehicle carried to launch altitude and released from beneath a carrier aircraft) or the Raptor 2 (air-launched from a C-17 using parachute-based extraction) provides air launched contractor based options until US Air Force transport aircraft can be modified as an airborne launch control center. Another design is AirLaunch's QuickReach booster, currently in the concept development phase. AirLaunch is designing QuickReach to launch to orbit after airdrop from an unmodified C-17 or other large cargo aircraft.[38]

Air launched options can transit and launch from virtually any orbital insertion point on any launch azimuth. Air launch has favorable incentives of launching directly from the equator, reducing required thrust for easterly launches, and over open water at any azimuth with no flyover restrictions of population centers. Further, air launched options bypass local weather problems such as fog and lightning that can delay ground launches. Ground basing, however, provides a routine low-cost operational capability and, as mentioned above, options currently exist to utilize a large quantity of former ICBM boosters. At least two options for launching in each medium are optimal in order to avoid grounding the entire fleet due to a mishap of a specific booster and a correspondingly lengthy failure investigation.

The Three-Tiered Approach

A tiered approach enables purposeful technology maturation within a determined and continuous approach to spacecraft and booster design, test, evaluation, and innovation. It should do so through standardized interfaces while leveraging and reorganizing existing organizational processes and products. Tier I should be an integrated research, development, analysis, and testing period that presents a variety of advanced and even elegant technical solutions to long-range problems. Tier I is thus *a Concept and Technology Development Phase*, designed to reduce risk and determine the appropriate set of technologies to be integrated into a full system. The initiative should only exit Tier I when an affordable increment of militarily-useful capability is identified, the technology for that increment has been demonstrated in a relevant environment, and a system can be developed for production within a short timeframe (normally less than five years).[39] Demonstration of payload technology in this phase could occur in a space chamber at Arnold Engineering Development Center, on a unmanned aerial vehicle or balloon platform, on an aircraft, or a test bench. Further, as the Air Force is the DoD Executive Agent for Space, an integrated partnership with research laboratories in national and DoD laboratories, academia, and industry along with specific agencies such as the Defense Advanced Research Projects Agency could be coordinated and led by the AFSTC and AFRL. The call for university research partnerships could thus be much more extensive, with AFRL and AFSTC sponsoring incentives and competitions—such as a ride to orbit—for award-winning technological demonstrations.

Tier II integrates these proven technologies on flight vehicles in order to demonstrate key performance parameters in their operating environment. In other words, industry builds experimental vehicles leading to a demonstration *(fly-off)* that results in an end of phase selection of production contractor with an initial production and deployment decision (Milestone C). Until now, this practice has been prohibitive due to a fixation on large, unique spacecraft with tailored launch vehicles and support platforms—and the lack of an AFSTC. The AFSTC enables this phase within a reasonable timeline, where prototypes are contractor built, but AFSTC launched, and followed by exhaustive AFSTC development test and evaluation to assess progress against critical technical parameters and early operational assessments. Past successes of the MSX and the XSS vehicles offer insight into the benefit of demonstrations before a production and deployment decision. These vehicles met critical on-orbit performance parameters and provided further insight into operational utility *before* a commitment was made to produce a constellation of vehicles.

The absence of this phase for space comprises the major difference between space acquisition and all other DoD acquisition programs (figure 4). The GAO recently reported that DoD must ensure that program officials demonstrate that they have captured appropriate knowledge at three key points—program start (Milestone B), design review for transitioning from system integration to system demonstration (where the design performs as expected), and production commitment (Milestone

C) as a condition for investing resources.[40] With a demonstration capability through the AFSTC, the Air Force could apply this model to spacecraft and space systems. The AFSTC determines the effectiveness and suitability of the system, and completion of Tier II rests on the decision by the Milestone Decision Authority (MDA) to either commit to the program at Milestone C or end the effort.[41] As mentioned above, experimental spacecraft can also potentially augment existing constellations until joined by production spacecraft or even operate in a stand-alone mode as demonstrated by the MSX spacecraft.

Tier III begins with the Milestone C production decision. Its purpose is to design a production strategy that meets cost, schedule, and quality targets. Industry will thus have significantly lower production and deployment risk because these risks were shifted to the technology and demonstration phases in Tiers I and II. This process ensures production lines have proven technologies, and a standardized payload interface to a common spacecraft bus allows room for expansion should technological breakthroughs occur during a production cycle. A spacecraft will then be able to proceed through spiral development without major design changes and corresponding delays.

"New objectives and new money cannot solve these problems. They could in fact, aggravate them further—unless every scientist, every engineer, every serviceman, every technician, contractor, and civil servant gives his personal pledge that this nation will move forward, with the full speed of freedom, in the exciting adventure of space." - President John F. Kennedy

This three-tier process provides a purposeful strategy to provide needed spacecraft capabilities on-orbit by lowering the technological, and thus programmatic, risk. This three-tier approach brings space acquisition more in-line with the DoD acquisition cycle and the commercial best practices model advocated by the GAO. Space acquisition programs have historically attempted to achieve full capability in a single step and serve a broad base of users, regardless of the design challenge or the maturity of technologies.[42] Managing requirements, developing technology within the science and technology environment while leveraging government, university and industry research capabilities, developing a purposeful and intensive test and evaluation capacity to demonstrate competing capabilities, and using mature technologies for production and operation are all encompassed within this three-tiered approach. These factors have been repeated recommendations from the GAO, who advocated these industrial best practices that enable commercial projects to meet cost and schedule targets. Further, it enables systems to be built and flown with available and *demonstrated* technology with the added benefit of evolving as technology matures by interfacing with common *plug-and-play* components.

Conclusion

Overcoming the problem of getting spacecraft to orbit in a routine fashion is crucial to shifting from the current paradigm of large, unique DoD spacecraft and launch vehicles. Launch failures—unsuccessful attempts to place a payload into its intended orbit—are bound to occur in the future, despite the fact of currently touting a success record of 47 consecutive US (commercial, civil, intelligence, and DoD) launches since the last failure in 1999, and 12 for 12 successful launches of EELV. Even the *risk* of failure raises the threshold beyond the reach of nearly all potential capability suppliers and results in a different acquisition cycle for space systems. However, increasing launch transaction rates coupled with developing standardized buses and plug-and-play interfaces changes the risk mitigation strategy. These practices would enable the United States to lower the opportunity cost of placing payloads into LEO and simultaneously increase the ability to put research and development payloads into space. This stands in stark contrast to the current method of attempting to achieve a quantum leap in technological capability, which leads to late deliveries, cost increases, and a high consequence of failure.[43]

Central to the spacepower paradigm shift is the addition of a true test and evaluation phase by creating the AFSTC. In-depth government expertise at the AFSTC enables proper program start decisions for spacecraft and launch vehicles that are in place for all other DoD program start (Milestone B) and production commitment (Milestone C) decisions. **With the AFSTC, and a corresponding system development and demonstration phase with robust test and evaluation, the DoD is no longer forced to treat space acquisition as separate and distinct.** This recommended three-tier program, similar to the DoD standard acquisition system, allows for production and deployment decisions only *after* successful demonstration of existing technologies. ***The proposed demonstration phase—Tier II—is therefore the major shift from current practice,*** combining the best practices model from industry and the existing DoD acquisition policy to ensure space system designs perform as expected in their operational environment.

These recommendations depend on each other for success. An on-orbit demonstration leads to producing spacecraft as needed within a given technological state of the art, a responsive launch capability ensures routine access to space, standardized spacecraft bus versions ensure program managers focus on improving spacecraft payloads, and *plug-and-play* interfaces enable modularizing inevitable technological advances. Together they provide the capacity to upgrade systems in a spiral fashion as technology matures during their production cycle instead of the current method of freezing the system design—and the given technological solution—years ahead of actual operational use.

The AFSTC enables, and is enabled by, these capabilities.

AFSTC detachments on both US launch ranges should consist of missile maintenance technicians and officers, working together with a small cadre of engineer and space operations officers. These personnel will conduct AFSTC demonstration-phase launches in-line with training and exercising, and in fact validating, their mission to integrate, test and launch a standard plug-and-play booster and spacecraft within days of a launch order from USSTRATCOM. In this sense, rather than continuing to rely on unproven new contractor starts, the AFSTC directly contributes to a true responsive space launch capability utilizing Air Force people and equipment to their potential. The AFSTC ultimately ensures the United States has a reliable rapid launch capability in the near term. Together, the AFSTC, the SBPO, and the three-tiered approach comprise a paradigm shift intended to increase the solvency of spacepower. This increased solvency will guarantee US political leaders and military commanders can continue to depend on military spacepower, and that it remains a continuing competitive advantage for the United States.

Notes:

[1] Edward F. Bruner, "Military Forces: What Is the Appropriate Size for the United States?" ed. Congressional Research Service (The Library of Congress, 2006). Throughout the Cold War, end strength of the US active duty force never dropped below two million personnel and peaked at over 3.5 million during the Korean and Vietnam Wars. Since 1989, end strength dropped steadily from 2.1 million to now less than 1.4 million.

[2] Dr. Loren B. Thompson, *Can the Space Sector Meet Military Goals for Space?* (The Lexington Institute, October 2005 [cited 15 May 2006]), http://www.lexingtoninstitute.org/docs/662.pdf (accessed 25 September 2006).

[3] Rich Tuttle, "Lt. Gen.: AF Space Program Woes Hurting Army Capabilities," *Aerospace Daily & Defense Report*, 26 January 2006.

[4] Senator Wayne Allard, speech given to the National Defense Industrial Association, Space Policy & Architecture Symposium (web site of US Senator Wayne Allard, 23 September 2005) http://allard.senate.gov/public/index.cfm?FuseAction=Legislation.ViewIssue&IssuePosition_id=1601 (accessed 25 September 2006).

[5] Marcia S. Smith, *Military Space Programs: Issues Concerning DoD's SBIRS and STSS Programs* (The Library of Congress, 25 November 2005) http://www.cnie.org/NLE/CRSreports/05nov/RS21148.pdf (accessed 25 September 2006). The Nunn-McCurdy act resulted from the Defense Authorization Act for Fiscal Year 1982, when Senator Sam Nunn (D-GA) and Representative David McCurdy (D-OK) included language intended to limit cost growth in major weapons programs. Programs that exceed a 15 percent Program Acquisition Unit Cost (PAUC) requires notification to Congress. If programs exceed a 25 percent limit, DoD must notify Congress and certify that the program is essential to national security, that no alternatives will provide equal or greater military capability at less cost, that new cost estimates are reasonable, and that the program management structure is adequate.

[6] Jim Wolf, "US Delays Pivotal Military Satellite Project," *Washington Post*, 6 February 2006.

[7] Richard Wolf, "How Federal Spending Has Climbed since 2001," *USA Today*, 3 April 2006, http://www.usatoday.com/news/washington/2006-04-02-federal-spending-inside_x.htm (accessed 25 September 2006).

[8] Jonathan Karp, Andy Pasztor, and Greg Jaffe, "Pentagon Weighs Personnel Cuts to Pay for Weapons," *Wall Street Journal*, 5 December 2005, http://online.wsj.com/public/article_print/SB113375156217213824-oPaL6D0OtfBQrfLvKmqwidSnwWE_20061205.html (accessed 25 September 2006).

[9] Jackie Calmes, "Pentagon's Blank Check May Be Withdrawn," *Wall Street Journal,* 10 March 2006, 6.

[10] Richard K. Betts, "Is Strategy an Illusion?," *International Security* 25, no. 2 (2000): 9.

[11] Staff Sgt. C. Todd Lopez, "Jumper Reflects on Challenges Facing Air Force," *Air Force Link*, 1 September 2005, http://www.af.mil/news/story.asp?storyID=123011549. General John P. Jumper, as outgoing Air Force Chief of Staff, stated, "The thing that worries me the most is the recapitalization of our force. We are now facing problems we have never seen before because of aging aircraft. We are having to deal with these aging airplane issues with an increasing amount of the budget, and we need to get on with recapitalizing."

[12] Mancur Olson, The Logic of Collective Action; Public Goods and the Theory of Groups, Rev. ed. (New York: Schocken Books, 1971). The free rider problem is a product of the behavior of collective action. Once a smaller member has the amount of collective good he gets free from the largest member, he has more than he would have purchased for himself, and has no incentive to obtain any of the collective good at his own expense.

[13] Robert E. Levin, "Overcoming Space Acquisition Problems," *High Frontier* 2, no. 2 (2006): 15.

[14] Robert E. Levin, "Space Acquisitions: Stronger Development Practices and Investment Planning Needed to Address Continuing Problems," GAO-05-891T, in testimony before the Strategic Forces Subcommittee, Committee on Armed Services, US House of Representatives (Washington, DC: United States Government Accountability Office, 2005), 9.

[15] Robert E. Levin, "Defense Acquisitions: Incentives and Pressures That Drive Problems Affecting Satellite and Related Acquisitions" (US General Accounting Office, 23 June 2005), 7.

[16] Thomas S. Kuhn, *The Structure of Scientific Revolutions,* 3rd ed. (Chicago, IL: University of Chicago Press, 1996), 6.

[17] Katherine V. Schinasi and US General Accounting Office, "Best Practices: A More Constructive Test Approach Is Key to Better Weapon System Outcomes," GAO/NSIAD-00-199 (US General Accounting Office report to Report to the Chairman and Ranking Minority Member, Subcommittee on Readiness and Management Support, Committee on Armed Services, US Senate, July 2000), 13.

[18] Katherine V. Schinasi and US General Accounting Office, "Missile Defense: Alternate Approaches to Space Tracking and Surveillance System Need to Be Considered" (US General Accounting Office report to Subcommittee on Strategic Forces, Senate Committee on Armed Services, 2003), 13.

[19] Air Force Flight Test Center, "Where We Stand Today," 1 March 2006, http://www.edwards.af.mil/base_guide/docs_html/history.html#top (accessed 25 September 2006).

[20] F-22 Raptor Flight Test, GlobalSecurity.org, http://www.globalsecurity.org/military/systems/aircraft/f-22-testfly.htm. The F-22 changed significantly from the YF-22 prototype. Specifically, the wingspan was increased, the wing leading-edge sweep was decreased, the vertical tails were reduced in area and moved aft, and the horizontal-tail surfaces were reconfigured. Each of the nine F-22s built in the Engineering and Manufacturing Development (EMD) phase was dedicated to flight test, and each of these aircraft were heavily instrumented to record flight test data. The nine aircraft will fly approximately 2,546 flights covering 4,583 test hours in EMD. The X-planes were significant because they were solely intended to develop technology in general, not lead to operational aircraft.

[21] United States Strategic Command, "Space Control," fact sheet, March 2004, http://www.stratcom.mil/fact_sheets/fact_spc.html (accessed 25 September 2006).

[22] Michael J. Sullivan and US General Accounting Office (GAO), "Technology Development: New DoD Space Science and Technology Strategy Provides Basis for Optimizing Investments, but Future Versions Need to Be More Robust," GAO 05-155 (United States GAO Report to Congressional Committees, January 2005), 2.

[23] Colonel Richard W. White Jr., SMC Det 12 Commander, telephone interview by the author, 3 April 2006.

[24] "Ball Aerospace Wins Space Test Satellite Contract," SpaceRef.com, Ball Aerospace & Technologies Corp., 1 April 2006, http://www.spaceref.com/news/viewpr.rss.spacewire.html?pid=19411 (accessed

September 2006).

[25]Col Richard W. White Jr.

[26]SMC Detachment 12, "History of Detachment 12," http://www.smc.kirtland.af.mil/ (accessed 25 September 2006).

[27]Statement of Arthur K. Cebrowski, Director of Force Transformation, Office of the Secretary of Defense, 25 March 2004, http://www.oft.osd.mil/initiatives/ors/Cebrowski%20Testimony.doc (accessed 25 September 2006).

[28]Michael J. Sullivan and US General Accounting Office (GAO), "Space Acquisitions: DoD Needs a Department wide Strategy for Pursuing Low-Cost, Responsive Tactical Space Capabilities," GAO-06-449 (US GAO Report to the Chairman, Subcommittee on Strategic Forces, Committee on Armed Services, House of Representatives, March 2006), 19.

[29]Douglas E. Lee, "Space Reform," *Air & Space Power Journal* 18, no. 2 (2004): 109.

[30]Ibid.

[31]Statement of Arthur K. Cebrowski, Director of Force Transformation, Office of the Secretary of Defense, in testimony before the Senate Subcommittee on Strategic Forces, Senate Armed Services Committee (Washington, DC: 2004).

[32]Gunter Dirk Krebs, "Lockheed Martin: A2100," Gunter's Space Page, 27 March 2006, http://space.skyrocket.de/index_frame.htm?http://space.skyrocket.de/doc_sat/lockheed_a2100.htm (accessed September 2006.

[33]Dr. William F. Ballhaus Jr., "Successes and Challenges in Transforming National Security Space," *High Frontier* 2, no. 1 (2006): 16.

[34]Sullivan and GAO, "Space Acquisitions: DoD Needs a Departmentwide Strategy for Pursuing Low-Cost, Responsive Tactical Space Capabilities," 6.

[35]Orbital Sciences Corporation, *Minotaur Users Guide*, October 2004, http://www.orbital.com/NewsInfo/Publications/Minotaur_Guide.pdf (acccessed 25 September 2006. The author does not advocate any specific corporate product. In this case, the US Air Force has already paid the development, production, and maintenance costs of these missile stages.

[36]Tech Sgt Timothy Hoffman, "Air Force Space Command Reworking How It Gets to Space," *Air Force News,* 14 May 1998, http://www.fas.org/spp/military/program/launch/n19980514_980661.html (accessed 25 September 2006).

[37]John Croft, "Changing the Low-Cost Launch Game," *Aerospace America,* February 2004, 42.

[38]Jeremy Singer, "Responsive Space Launch," *Air Force Magazine* 89, no. 3, March 2006, http://www.afa.org/magazine/march2006/0306space.asp (accessed 25 September 2006).

[39]Edward C. Aldridge Jr., *Operation of the Defense Acquisition System,* Department of Defense, 5000.2, 12 May 2003, http://www.dtic.mil/whs/directives/corres/pdf/i50002_051203/i50002p.pdf (accessed 25 September 2006).

[40]Michael J. Sullivan and US General Accounting Office (GAO), "Defense Acquisitions: Major Weapon Systems Continue to Experience Cost and Schedule Problems under DoD's Revised Policy," GAO-06-368 (US GAO Report to Congressional Committees, April 2006), 23.

[41]Edward C. Aldridge Jr., *Operation of the Defense Acquisition System*.

[42]Sullivan and GAO, "Space Acquisitions: DoD Needs a Departmentwide Strategy for Pursuing Low-Cost, Responsive Tactical Space Capabilities," 15.

[43]Ibid., 20.

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Figure 1. Source: Reprinted from Robie Samanta Roy and Ray Hall, "The Long-Term Implications of Current Plans for Investment in Major Unclassified Space Programs," ed. Congressional Budget Office (US Congress, 2005): 3.

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Maj John Wagner (BS, Astronautical Engineering, USAFA; MBA, University of Maryland; MS, Astronautical Engineering, Air Force Institute of Technology) is the Operations Officer of the 45th Launch Support Squadron. He was first assigned to Cape Canaveral AFS, Florida as the Titan IV heavy launch vehicle propulsion engineer and later responsible for Titan mechanical systems, payload fairings and payload integration for national security spacecraft. In that capacity, he directed pad operations for the successful launch of the first MILSTAR and three other classified spacecraft that continue to enhance US national security. He also led the successful solid rocket motor launch pad destack/restack in 1993-94.

In 1996, Major Wagner was assigned as a space-based missile warning Flight Commander at the Defense Support Program's European Ground Station. He later served as an Operations Evaluator and the Commander, Operations Support Flight, responsible for training, crew force management, operational procedures, and mission analysis, resulting in 100 percent launch detection and 99.9 percent system availability rates—best in Air Force Space Command (AFSPC).

In 2000, Major Wagner was assigned to the Space Warfare Center as the Chief of Advanced Technology and later as the Deputy Chief of the Wargaming and Simulation Branch. In that capacity, he was the Operations Director for the first US space-centric wargame, Schriever 2001, and Game Director for Schriever II, the first coalition and interagency space wargame. Major Wagner later served as the speechwriter for the Commander of AFSPC, authoring congressional testimony, posture statements, command priorities, and over 200 national and international articles, briefings, and speeches.

Major Wagner was the 2002 winner of the Rotary National Award for Space Achievement. He was a distinguished graduate from Undergraduate Space and Missile Training, Squadron Officer School, and Air Command and Staff College. He is a 2006 graduate of the School of Advanced Air and Space Studies, and this article is a small subset of his thesis, *Increasing the Solvency of Spacepower*.

Industry Perspective

Evolved Expendable Launch Vehicle: Assuring Access to Space

Mr. Daniel J. Collins
Vice President,
Launch Systems, Network and Space Systems
Boeing Launch Systems

Americans depend on access to space. We depend upon it for our national security; we depend upon it for our personal safety and well-being; we depend upon it for our national economy … simple, true, statements. Yet the reality of assured access to space is considerably more complex and elusive. For the past six years, government and industry have worked together to develop approaches to provide assured access through the Evolved Expendable Launch Vehicle (EELV) program. It has been a difficult path. Basic underpinnings of requirements used to initiate the program have shifted dramatically. But we have never been closer to achieving this goal. A congressionally-mandated panel, led by Lt Gen Forrest S. McCartney, USAF, retired, recently concluded in its National Security Space Launch Report that: "The EELV development programs are true successes and are critical to national security."[1] This testimony, combined with a perfect launch record, provides the national security space community with a clear indication that we are on the path to success.

The Dogleg Trajectory to Success

In October 1998, Boeing and Lockheed Martin entered into contracts with the US Air Force to develop new families of launch vehicles and provide launch services to the US government. The contract anticipated that, for the next 20 years, EELVs would be the basis for intermediate and heavy space access for the US national security space community. The Air Force provided approximately $500 million to each contractor to offset a portion of system development cost, and the contractors agreed to self-fund the remaining development cost and infrastructure. Industry contributions exceeded the government investment several times over. The government also provided a sort of anchor tenancy by procuring a total of 28 launches from the two contractors.

Dramatic changes in the launch industry buffeted the incipient program well before it cleared the tower. At least two of these called into question the fundamental assumptions of the program. First, a string of launch failures in 1998 and 1999 led to a Broad Area Review (BAR) and prompted questions regarding the validity of insight versus oversight. Following the BAR, government and industry increased independent reviews and instituted increased mission assurance activities.

The second major shift was the collapse of the commercial launch market. In 1998, Commercial Space Transportation Advisory Committee (COMSTAC) estimated that there would be over 250 payloads launched into orbit in 2002. The EELV program was initially based on the assumption that commercial demand would drive down prices and increase system reliability. The prime contractors priced their launch services accordingly. By the time 2003 actually arrived, however, COMSTAC was predicting that the number of satellites launched would hover well under 50 a year for the foreseeable future. With this shift, the high-fixed costs of launch production could only be spread over a much smaller launch number of vehicles per year. Costs per vehicle went up to the point where it became difficult, if not impossible, for EELVs to compete with highly subsidized foreign launch providers. The EELV contractors found themselves in a position where they could not make a profit on contracted launches. Ultimately, this market shift required increased funding and led to a Nunn-McCurdy breach.

Realizing the current situation was unsustainable, the White House developed a new National Space Transportation Policy (NSTP) which was authorized by President George W. Bush on 21 December 2004. The NSTP specified policies which would provide a solid policy foundation for EELV through 2010. The policy specifies that:

> "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 US 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.
>
> "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 service providers …"[2]

The resulting Buy III contract converted NSTP policy implementation guidelines into sound acquisition strategy. The original requirements for the EELV program were translated into the Operational Requirements Document (ORD), and the System Performance Requirements Document which specified a set of requirements for the EELV program.

In spite of the extraordinary difficulties of shifting from a commercial (FAR Part 12) to a traditional government oversight contract (FAR Part 15), the Air Force and contractors are finding ways to make the transition work.

Meeting the Nation's Needs for Assured Access

The importance of operational reliability cannot be over-emphasized. The McCartney-led study stresses this point:

> "Some NSSI [National Security Space Institute] 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 NSSI 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."[3]

One of our first areas of emphasis was in defining a set of design requirements which encompassed a wide variety of missions. So each member of the vehicle family exceeds the most stressing mission requirements for any mission. The result is higher mission assurance across the vehicle family. Working with the US Air Force and The Aerospace Corporation, we validated our designs through a detailed and rigorous process of design reviews, tests, configuration audits, and independent validation and verification. Analytically, the Delta IV has a mission reliability exceeding 98 percent. Practically speaking, we have completed our missions successfully on all six of our launches. The Atlas program has earned a similar level of reliability. Combined, the EELV program is 14 for 14. This is an exceptional record for two completely new launch systems.

US Air Force requirements also called for the capability to launch a broad range of satellite payloads into virtually every conceivable orbit. These requirements included 13,500 lbs. to geosynchronous earth orbit and a range of masses to polar orbit from 4,400 lbs. to 41,000 lbs. No single vehicle or launch range could meet this spectrum of requirements. Translated to hardware, the ORD meant that EELV providers needed to have an entire family of vehicles and launch facilities on both the East and West Coasts.

Figure 1. Delta IV EELV Family.

The Delta IV program meets these requirements with a completely integrated launch infrastructure: new vehicles, new factory, new launch pads, and new logistics systems. The first launch of Delta IV took place only four years from contract award—a remarkable achievement for the Air Force and the Boeing Delta team.

The Delta IV family of launch vehicles is a versatile, capable launch system. With payload capacities ranging from the Delta IV medium capacity of just over 9,000 lbs. to low Earth orbit, to the Delta IV heavy capacity of almost 49,000 lbs., the family covers the range of US government payload mass requirements in the intermediate and heavy classes. The Delta IV family also offers either four- or five-meter-diameter payload farings, depending on vehicle configuration.

In the late 1990s the US national security community saw the potential for high flight rates in the future, and built these requirements into the ORD. Effectively, these flight rate requirements meant that as many as 34 Common Booster Cores (CBCs) might have to be produced in a single year. The Delta program responded. The CBC was designed for produceability through design commonality and reduced parts count. The RS-68 engine, for example, has only 5 percent of the parts count of the Space Shuttle Main Engine.

Figure 2. Decatur, Alabama Production Facility.

The Decatur, Alabama production facility was sized to meet these requirements. Designed to produce as many as 40 CBCs a year, it is a state-of-the-art production facility. The facility is arranged with a linear production line, with materials coming in one end of the factory, and rockets exiting the other. State-of-the-art production techniques are incorporated throughout the factory. While we struggle with the low production rates demanded by the current market, the early results have been impressive. The Friction Stir Welding facility has performed more than 120,000 linear inches of welding without a single flaw or defect. The environmentally clean Spay On Foam Insulation process has applied more than 100,000 square feet of insulation without defects. Certainly, the Decatur plant warrants the moniker: national asset.

Mission requirements also necessitated that EELVs have the capability of launch from both Cape Canaveral Air Force Station (CCAFS), Florida and Vandenberg AFB, California (VAFB). The Delta program developed launch pad infrastructure which

Figure 3. NROL-22 Launch from the West Coast.

featured horizontal vehicle integration. Our launch system was also designed with the capability of automated vehicle checkout, off stand, in the Horizontal Integration Facility. The system was designed to minimize the amount of time necessary on stand, with a design objective of eight days.

Launch vehicles are transported to either CCAFS or VAFB in the Delta Mariner, a ship specifically designed to carry launch vehicles with the capability to operate in both inland waterways and the open seas. As with every other element of the Delta IV system, the launch and logistics systems were designed with the intent of meeting US government requirements for reliability, availability, and efficiency.

The ORD also challenged the EELV program to be at least 25 percent less expensive to operate than existing systems, with an objective of 50 percent. The Delta program has met this challenge in two ways. First, since the Delta program was largely funded by Boeing, the Air Force avoided the development cost spike associated with most programs. Secondly, the operational cost of the Delta program is projected to be approximately 50 percent of the Titan program.

To be sure, there is much work to do in this area, but the Nation should be able to achieve assured access at lower cost. Two factors should always be kept in the front of our minds, however. First, lower cost is not worth any compromise in reliability. Mission success is overwhelmingly the highest priority. In financial terms alone, the importance of launch success is obvious. In 1996, over $4 billion in payloads were launched at a cost of $1.2 billion. In 2007, that figure will be over $10 billion in satellites launched at a cost of $1.6 billion.

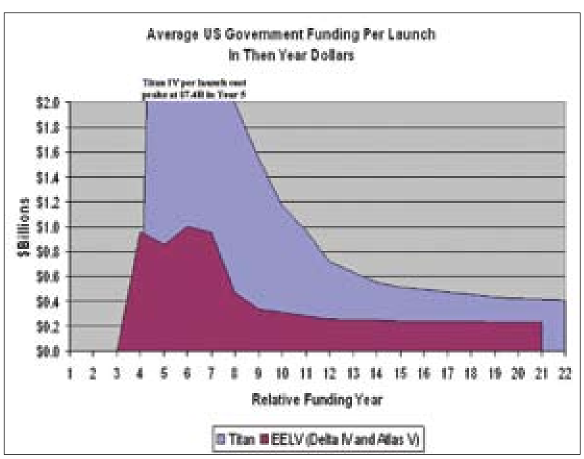


Figure 4. Titan versus Delta Costs Profiles.

Second, we should bear in mind that both EELV programs are relatively high up the learning curve. The typical launch vehicle programs run for over 20 years. Atlas and Delta have only been launching for four years. We have considerable industrial experience which indicates we will be able to gain considerable cost-efficiencies over time.

Passing Through MaxQ

In 1998, Boeing, Lockheed Martin, and the US Air Force committed to provide the Nation with assured access. Together we are meeting that commitment. The past few years have been difficult for the space acquisition business. But the Air Force and contractor partnership for EELV is emerging healthier than ever. We have passed through the most difficult phase of this program and emerged with two very capable launch vehicles, which are poised to meet US government mission requirements for the foreseeable future.

Notes:

[1] RAND National Defense Research Institute, "National Security Space Launch Report," XIX.

[2] National Space Transportation Policy, 21 December 2004, Office of Science and Technology, Assuring Access to Space, sect. I, bullet 4, subbullet A.

[3] RAND, 3.

Mr. Dan Collins (BS, Civil Engineering, Loyola Marymount University, Los Angeles) is the vice president of Launch Systems for Boeing Network and Space Systems, a major business unit of Boeing Integrated Defense Systems. In this capacity, he oversees the Delta launch vehicles, Sea Launch payload accommodations and Boeing Launch Services, the contract and marketing organization for the Delta and Sea Launch vehicles.

Prior to this position, he was vice president and program manager of the Delta program, responsible for overseeing the design, engineering, integration, production, quality assurance, and program management for the Delta II and IV launch vehicles, and the Titan payload fairing program.

Before this assignment, Mr. Collins was the vice president and program manager of the Boeing Evolved Expendable Launch Vehicle (EELV)/Delta IV, where he was in charge of the development and production of the Delta IV family of launch vehicles.

Prior to that, he directed program integration activities for the Delta IV EELV effort and was also the program manager for the Delta III launch vehicle.

Mr. Collins began his career at McDonnell Douglas in 1990 as a structural analysis engineer on the Space Station Freedom program. Since then, he has held several positions of increasing responsibility and served on the integrated product team for the International Space Station's pressurized elements.

Prior to joining McDonnell Douglas, Mr. Collins worked for the Northrop Corporation. He represents Boeing on the board of the Discovery Science Center in Santa Ana, California.

Assured Access to Space Space Transportation Perspective

Mr. Michael C. Gass
Vice President and General Manager of Space Transportation,
Lockheed Martin Space Systems Company

The Hard Lesson

On the bitterly cold Florida morning of 28 January 1986, the US space program was rocked to its foundation, and the policy of relying primarily on the Space Shuttle to loft national security payloads into space was shattered with the explosion of the Challenger. The Challenger loss exposed our vulnerability, and was followed in a matter of weeks by two other catastrophic rocket failures—the loss of a Titan 34D at Vandenberg AFB, California on 18 April and a Delta at Cape Canaveral, Florida on 3 May.

The wakeup call had become a nightmare.

That's because by 1986, America was already heavily dependent upon space-based systems for intelligence, communication, and missile early warning, and that dependence rested upon something policymakers had come to take for granted: routine access to space. As a result, for a breathtakingly long two-and-a-half years, the world's leading superpower was incapable of replenishing its critical space assets.

Officials at the time vowed to restore and strengthen the space launch fleet. A series of initiatives were formulated to address the deficiencies of past launch architectures and to realize the opportunities for renewal presented by the current crisis. Over much of the next decade the proposed means for addressing the problem of assured access would advance through several iterations—from Advanced Launch System, to National Launch System, to Spacelifter—eventually culminating in the Evolved Expendable Launch Vehicle (EELV).

The Atlas V, developed by Lockheed Martin Commercial Launch Services as part of the US Air Force EELV program.

Evolved Expendable Launch Vehicle Program Development Overview

The EELV program came into being as a result of a report issued in May 1994 entitled the "Department of Defense Space Launch Modernization Plan." Headed by then Lt Gen Thomas S. Moorman, Jr., Vice Commander of Air Force Space Command, the report evaluated the increasing costs related to the Department of Defense's (DoD) medium and heavy-lift launch vehicles. This study recommended four possible options to address the issue: (1) maintain the existing systems with minor upgrades, (2) evolve existing systems, (3) design and develop an all new expendable system, and (4) develop a new reusable system.[1]

The DoD chose the second option, to evolve existing systems, and in November 1994 created an implementation plan that would reduce the total cost for medium- and heavy-lift space launches. The EELV strategy envisioned the award "of a single production contract that would (1) maximize common systems and components to reduce procurement costs and enhance production rates and (2) decrease the number of launch complexes, launch crews, and support requirements to reduce operation costs."[2]

Following a Request for Proposals in May 1995, four companies were awarded 15-month Low Cost Concept Validation contracts in August 1995, each valued at $30 million, to expand and detail their EELV concepts. The companies were: (1) Alliant Techsystems Inc. of Magna, Utah, (2) Boeing Defense and Space Group of Seattle, Washington, (3) Lockheed Martin Technol-

ogies, Inc. of Denver, Colorado, and (4) McDonnell Douglas Aerospace of Huntington Beach, California.[3]

In December 1996, a downselect to two contractors—Lockheed Martin and McDonnell Douglas—was announced. Each received a $60 million contract to complete 17-month independent Pre-Engineering and Manufacturing Development studies for EELV. In August 1997, Boeing purchased McDonnell Douglas Aerospace and continued to perform the EELV contract.[4]

Not even a year into the EELV final selection competition, the US government shifted gears. In November 1997, it was announced that rather than choosing a single EELV contractor both companies—Boeing and Lockheed Martin—would continue forward with their development and manufacture of medium- and heavy-lift EELVs, and share the government market when the systems became operational.

The government rationale behind the decision arose from the perception that a burgeoning communications satellite market would help defray the costs of maturing two launch systems. But, a robust commercial launch market never materialized. Nevertheless, both EELV contractors continued forward. In 2002, both EELV systems would launch successfully, and have transitioned into the operational phase.

Defining Assured Access

The EELV will be the means to achieve assured access to space as codified in US Code Title 10, Section 2273, 24 November 2003, per Public Law 108-136:

> "It is the policy of the United States for the president to undertake actions appropriate to ensure, to the maximum extent practicable, that the United States has the capabilities necessary to launch and insert United States national security payloads into space whenever such payloads are needed in space. The appropriate actions referred to shall include, at a minimum, providing resources and policy guidance to sustain (1) the availability of at least two space launch vehicles (or families of space launch vehicles) capable of delivering into space any payload designated by the Secretary of Defense or the Director of Central Intelligence as a national security payload; and (2) a robust space launch infrastructure and industrial base."[5]

The concept of "assured access" is defined further in the US Space Transportation Policy, 6 January 2005:

> "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."[6]

The Atlas Evolved Expendable Launch Vehicle

The Atlas Launch System is an integral element of the "Assured Access to Space" strategic objective of the US Space Transportation Policy. The capabilities enabled by Atlas enhance the Nation's ability to secure peace, protect national security, lead exploration of the solar system and beyond, increase economic prosperity, and expand our knowledge of the Earth and its environment.

The Atlas Program is part of Lockheed Martin Space Systems Company (LMSSC) with production operations in Harlingen, Texas and San Diego, California; final assembly, engineering, and business operations in Denver, Colorado; and launch facilities at Cape Canaveral AFS, Florida and Vandenberg AFB, California. Atlas provides complete launch services including spacecraft integration, processing, encapsulation, launch operations, and verification of orbit.

In June 2007, the Atlas Program will celebrate the 50th anniversary of its first launch. The Atlas Program's legacy of innovation and accomplishment includes launching: the world's first intercontinental ballistic missile (ICBM), the world's first communications satellite, the first Americans to orbit the Earth, the first American spacecraft to soft land on the Moon, and spacecraft to every planet in the solar system. The Atlas team has demonstrated the ability to adapt to changes in space policy, foreign competition, and market demands.

During the late 1980s, the Atlas Program underwent a transition from National Aeronautics and Space Administration (NASA) management to a commercial program, which was autonomously managed and operated by General Dynamics (GD). In 1987, GD began marketing Atlas directly to commercial and government customers. In 1993, Martin Marietta acquired the Atlas Program from GD. In 1995, Atlas design and final assembly were moved from San Diego to Denver.

The hallmarks of the modern Atlas Program are relentless attention to mission success, pre-planned, low-risk evolutionary development, continuous product and process improvement, and focus on the needs of the customer. This intense focus on mission success and continuous process and product improvement were born from painful experiences at the start of the commercial program during which three of the 11 Atlas I launches resulted in failures.

Since 1990, the Atlas team has developed eight new vehicle configurations; each of which was fully successful on its inaugural flight. The Atlas V 400- and 500-series launch vehicles are the latest evolutionary versions of the Atlas launch system; they were placed into service in 2002. The recent launch of AV-008 was the 590th Atlas launch. It was also the 79th consecutive success for an Atlas booster with the Centaur upper stage. This record includes 100 percent success for the Atlas II, IIA, and IIAS families and all Atlas III and V vehicles. It also includes launches from four launch pads on two coasts.

The Atlas IIAS and Atlas III vehicles were successfully flown out in 2004 and 2005, respectively and are no longer in production. The Atlas V vehicle has launched successfully eight out of eight times and is maintaining an annual rate of four to six launches per year with a surge capability of 12-18 vehicles per year. Atlas recently added to its legacy of support to interplanetary exploration, launching back-to-back NASA missions to Mars in 2005 and Pluto in 2006.

The primary requirements of the EELV program, as defined by the US government, are to:

1. Provide launch services for DoD and NASA payloads at a minimum 25 percent reduction in recurring costs (as compared to heritage systems) while improving reliability, capability, and operability;
2. Provide a minimum design reliability of 0.98;

3. Accurately deliver payloads to their required orbits, including geosynchronous transfer orbits (GTO);
4. Provide standardized payload interface capabilities.

The Atlas team successfully met and surpassed each of these requirements. Using the launch rates baselined during the EELV competition, the Atlas V family reduced the cost to orbit by 50 percent. The Atlas V 401 (10,900 lbs. to GTO) has a design reliability of .995. The Atlas V 551 (19,180 lbs. to GTO) has a design reliability of .992. Demonstrated reliability is 100 percent, system performance requirements have been substantially exceeded and orbital errors on launches to date have been fewer than 25 percent of the allowable.

The Atlas Program is in the recurring or production phase of its lifecycle. However, product and process improvements are implemented on an on-going basis to meet the dynamic needs of the customer community and to ensure sustained mission success. Recent upgrades include a redundant avionics control system and more reliable and producible solid rocket motors. Advanced design work is also being accomplished for the next generation of Atlas to provide even greater performance and higher reliability to address the country's future space transportation needs.

Current Space Transportation Approach Enables Assured Access

The US government has put into place the necessary legal, policy, and contractual mechanisms to allow for the EELV program to stabilize and be poised for increased efficiencies in the future. As has been described previously, the desire of the government to have assured access to space and maintain two viable launch providers has required it to establish and fund capability contracts with the EELV providers. This enables the country to maintain the baseline critical skills and capabilities required to meet current and future access to space needs. Once this critical baseline has been established through the increased level of insight by the government the next step will be to increase the overall efficiency of acquiring assured access to space capabilities without sacrificing overall system reliability.

The United States is approaching a crossroads in the space transportation area. We can either sustain two existing EELV providers until a downselect is required due to budgetary constraints, or improve the economic efficiency of the two launch systems to enable sustained assured access. The first option requires no additional action on the US government's part, and the second requires an integrated government and industry plan.

I would like to pursue the second alternative and propose some thoughts on how this could be accomplished, as well as identify those specific challenges the US government needs to be addressing. The second alternative will be made possible through multiple, parallel paths, (1) continuous improvement of the existing fleet of vehicles, (2) near-term new market op-

Atlas V launch of the NASA New Horizons spacecraft mission to Pluto on 19 January 2006.

portunities, and (3) the proposed Joint Venture United Launch Alliance.

One of the successes of the Atlas family of launch vehicles has been the continuous incorporation of new technologies and processes into the launch system. These have provided Atlas with new capabilities, increased reliability, and lowered costs relative to earlier versions of Atlas vehicles. This process of continuous improvement also has kept the Atlas workforce fresh, always looking for innovative technologies or processes to improve their fleet. It has resulted in eight new Atlas vehicle configurations developed over 15 years with 100 percent mission success throughout, equating to a new vehicle configuration every two years. The last thing that the United States can afford to do is restrain that spirit of innovation and settle for "good enough."

The second aspect of addressing future challenges is expansion of the addressable marketplace for EELV launch vehicles. The net result is higher volume at factories and launch pads, resulting in decreased costs and increased efficiencies of procedures and processes. The near-term commercial market outlook continues to look flat, but there are other opportunities that could help address this aspect. Specifically, the NASA requirement for regular International Space Station re-supply missions could provide the EELV production and processing lines with the additional flights per year that could decrease costs associated with the vehicles while maintaining a "healthy" flow of products through the factory and launch processing to preserve skill levels.

The last area of discussion is the proposed joint venture between Lockheed Martin and The Boeing Company, the United Launch Alliance (ULA). This combination, if approved, will provide the potential for future synergies and cost reduction associated with integrated management, manufacturing, and launch operations for both the Atlas V and Delta IV family of vehicles. ULA also maintains the two separate launch vehicle systems to address the government's desire for assured access to space as currently defined.

Conclusion

While assured access to space from a warfighter perspective encompasses much more than launch, the fact remains that all space assets have to get to space to be effective. Therefore, space transportation is a critical and necessary component of any space architecture. The US government has established the necessary components, legislation, policy, and acquisition strategy, to enable the national security space community to provide assured access to space capabilities to the warfighter today and in the future.

The challenge for the US government is to not become complacent and accept "good enough," but rather to continue to improve the capability that exists today through continued injection of new technology and improved processes, thus enabling the use of these space transportation systems to support multiple government missions, while taking full advantage of the capabilities the proposed joint venture can provide. This will guarantee that assured access to space continues to be available in the long term, while supporting the management of critical sub-tier industrial base suppliers that without this approach would not continue to operate efficiently, if at all.

Since the beginning of our Nation's space program, we have benefited from inspired leadership within the DoD and NASA, from both the uniformed services and civilian leadership. Indeed, our national security depends on such leadership to retain American pre-eminence in space. To leaders like these, the wakeup call of January 1986 became a call to action. We in industry must continue to perform and deliver on the promises of assured access to retain our pre-eminence on the high frontier.

Notes:

[1] GlobalSecurity, "EELV Evolved Expendable Launch Vehicle," GlobalSecurity.org, 2005, http://www.globalsecurity.org/space/systems/eelv.htm. (accessed 25 September 2006).

[2] Ibid.

[3] Ibid.

[4] Ibid.

[5] Policy regarding assured access to space: national security payloads, Cornell Law School, Legal Information Institute, US Code: Title 10, Subtitle A, part IV, chapter 135, § 2273, 2006, http://www4.law.cornell.edu/uscode/html/uscode10/usc_sec_10_00002273----000-.html (accessed 25 September 2006).

[6] US Space Transportation Policy, 6 January 2005, http://www.ostp.gov/html/SpaceTransFactSheetJan2005.pdf (accessed 25 September 2006).

Mr. Michael C. Gass (BS, Industrial Engineering, Lehigh University; MS, Management, Massachusetts Institute of Technology) is the vice president and general manager of Space Transportation for Lockheed Martin Space Systems Company, responsible for the Atlas, Titan, and Advanced Space Transportation product lines and all space launch activity.

Prior to this assignment, Mr. Gass served as vice president, Atlas/Evolved Expendable Launch Vehicle (EELV) programs, for Lockheed Martin Space Systems and as vice president of the Atlas launch vehicle program. He was responsible for the Atlas II, III, and V launch vehicle programs, and held additional senior operational and management positions.

Mr. Gass also served as vice president of Production and Materiel Operations with responsibility for all Lockheed Martin Astronautics launch vehicle and spacecraft programs. Before this position, he led the Atlas launch vehicle final assembly and tank fabrication areas through the transition phase of an accelerating production rate and relocating the operation from San Diego, California to Denver, Colorado.

Mr. Gass served in a number of management positions with General Dynamics for 14 years before its Space Systems Division was acquired by Martin Marietta, which merged with the Lockheed Corporation in 1995 to become Lockheed Martin Corporation.

Industry Perspective

Sea Launch – Providing Assured Commercial Access to Space

Mr. Rob Peckham
President and General Manager,
Sea Launch Company, LCC

Amid the bustling of one of the world's largest commercial ports, in Long Beach, California, members of the international Sea Launch team work together to ensure mission success and customer satisfaction. A testament to both the complexities and abilities of multiple cultures and disciplines working synergistically in a cooperative commercial enterprise, Sea Launch optimizes expertise and technology from parties that have teamed up for peaceful, profitable objectives. Sea Launch Company, LLC, manifests a unique concept—the marriage of marine and rocket technologies, driven by the focused dedication of meeting customer requirements.

Established in April 1995, Sea Launch is an international consortium of four of the world's top space and marine companies. Boeing Company (US, 40 percent), RSC Energia (Russia, 25 percent), Aker ASA (Norway, 20 percent), and SDO Yuzhnoye/PO Yuzhmash (Ukraine, 15 percent) formed a partnership that would be the first, and only, company to launch commercial satellites from a sea-based platform positioned on the equator in the Pacific Ocean.

With its unique capability of launching at a zero-degree inclination, Sea Launch maximizes satellite lifetime on-orbit and offers customers the potential for additional transponder revenue. Into its eighth year of commercial operations, Sea Launch has attracted new and repeat customers such as XM Satellite Radio, DIRECTV, Thuraya Satellite Telecommunications Company, Inmarsat, Intelsat/PanAmSat, EchoStar Communications, SES Global, JSAT Corporation, KT Corporation, and spacecraft builders Space Systems/Loral, Boeing Satellite Systems, EADS Astrium, Lockheed Martin Commercial Space Systems, and Alcatel Alenia Space—who rely on Sea Launch and its world-class service to help grow their businesses. As a result, Sea Launch has emerged as the most innovative, commercially competitive, reliable, heavy-lift launch service in the industry.

The Sea Launch partners are fully committed to the long-term success of Sea Launch. It is a prototype that exemplifies the potential for global cooperation, for the purpose of serving a global market. In addition to achieving 22 successful missions by October of 2006, an additional measure of Sea Launch's success is its robust manifest, during a relatively flat market for commercial satellite demand.

Located on the Equator at 154° West Longitude in international waters of the Pacific Ocean, the launch site is utilized solely by Sea Launch and provides the most direct route for spacecraft on their way to geostationary orbit. This site offers maximum lift capacity, which enables customers to launch increased spacecraft mass or reap the financial benefits of extended satellite life on-orbit. Dubbed the "doldrums" for a lack of inclement weather conditions, the launch site provides a benign environment as well as launch schedule assurance.

Sea Launch Company

Launch of the Koreasat-5 Satellite, 21 August 2006.

The Sea Launch partnership thrives in its diversity with each of the parties adept in its respective field of expertise, complementing the team as a whole. The ability to optimize its resources is imperative as the Sea Launch system integrates systems and technology not usually designed to work together or in confined spaces. Marine technology forms the foundation of the innovative *Odyssey* Launch Platform that is managed by the Norwegians and is home to the launch pad. The Ukrainians design and manufacture the Zenit-3SL vehicle, a modified ver-

Galaxy 16 Mission, June 2006.

XM-4 Mission, 30 October 2006.

sion of the reliable and quick-response system they brought into operation in the early 1980s. The system also incorporates the reliable Russian Block-DM upper stage, which deploys satellites into geosynchronous transfer orbit. The Americans provide mission design and management, systems integration, and payload accommodations.

From the Launch Control Center on the accompanying vessel, the *Sea Launch Commander,* the launch team controls the fully automated rocket remotely throughout launch operations, including the assembly of the rocket on the launch pad, automatic mating of fueling and electrical umbilicals, countdown, liftoff, and flight. With the nearest land being a tiny island some 250 miles away, the 300 personnel at the launch site depend on the resources of the two vessels for all professional, operational, and personal needs.

It is the dynamic Sea Launch team—as well as the launch system itself—that truly sets the operation apart from other launch service providers. A lean, dedicated, experienced group of professionals, each individual accepts tremendous responsibilities, as well as the authority to carry them out. Each member is a stakeholder with a personal investment in meeting customers' requirements and assuring successful missions. And each member realizes the results of the team's collective accomplishments.

Launch of the Koreasat 5 Satellite, 21 August 2006.

Emphasizing responsive, flexible and innovative customer-focused solutions, the Sea Launch team works closely with spacecraft end users, manufacturers, and the insurance community to ensure open relationships and uncompromised customer satisfaction. Sea Launch continues to build its legacy, one successful mission, one satisfied customer, at a time. Additional information about the Sea Launch Company is available on the company web site at www.sea-launch.com.

Mr. Rob Peckham (BA, California State University, Chico; MBA, Pepperdine University) became President and General Manager of the Sea Launch Company in June 2006. He is responsible for the leadership and management of the international team of seasoned professionals who support the commercial launch needs of the international space community with the proven and reliable Sea Launch system and its land-based derivative, Land Launch.

Prior to assuming his present position, Mr. Peckham was Vice President of Sales and Marketing for Sea Launch, since 2001. He was Manager of Launch Services Acquisition for Hughes Space and Communications before joining the Sea Launch team in 2000, as senior director of Sales and Marketing.

Mr. Peckham entered the aerospace industry in 1980, at the Northrop Corporation, and began his commercial space career in 1988, working on the Delta II program at McDonnell Douglas Astronautics Company in Huntington Beach, California. Since that time, he has held increasingly responsible positions in the development of commercial space programs.

Enhancing Joint Space Operations

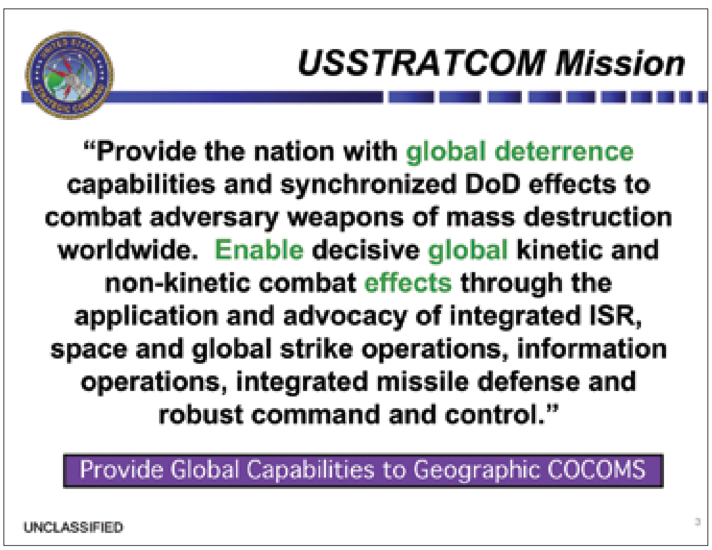
Lt Gen C. Robert Kehler, USAF
Deputy Commander, US Strategic Command

"CDR JFCC SPACE will direct the continuous planning and execution of assigned space operations missions. When tasked, CDR JFCC SPACE will participate in adaptive planning and develop courses of action for space effects for USSTRATCOM and national objectives."

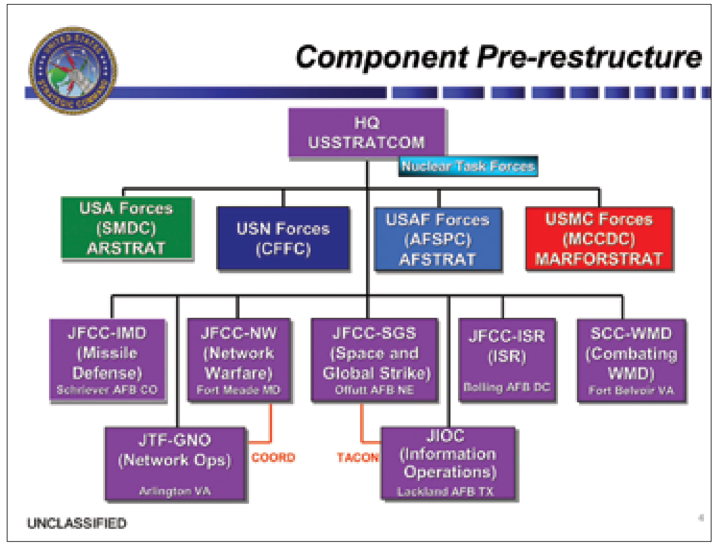
- General James E. Cartwright, Commander, USSTRATCOM
JFCC SPACE Implementation Directive, 19 July 2006

A New Direction

In May 2004, General James E. Cartwright, Commander, US Strategic Command (USSTRATCOM), began implementing a series of dramatic and comprehensive organizational changes. These organizational moves were undertaken in response to direction contained in Unified Command Plan 2002, which deactivated US Space Command, created US Northern Command, and added multiple missions beyond STRATCOM's legacy nuclear deterrence responsibilities. In essence, STRATCOM became a renewed global command focused on delivering integrated strike, space, missile defense, network warfare, and intelligence, surveillance, and reconnaissance (ISR) combat effects to the Geographic Combatant Commands.

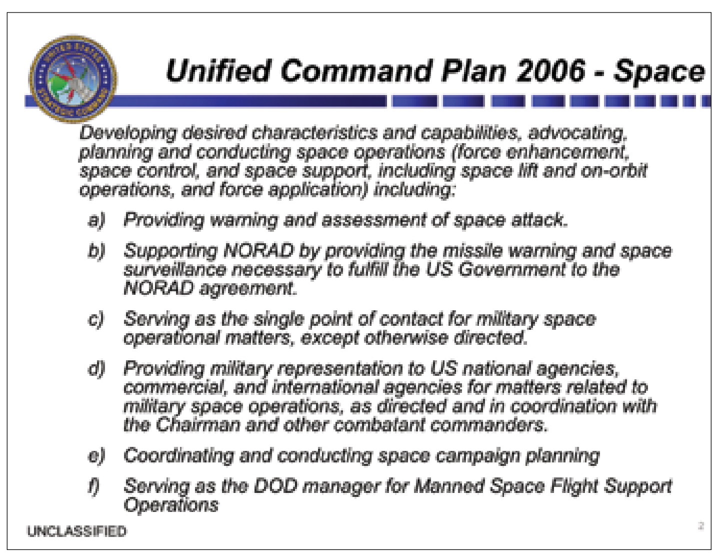


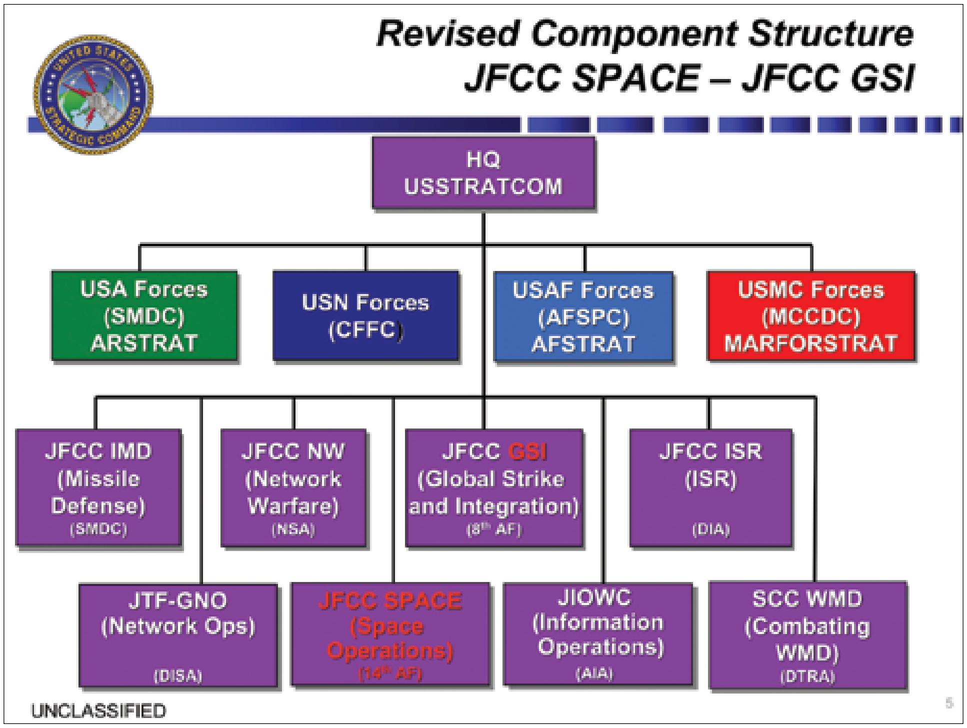
The creation of Joint Functional Component Commands (JFCC) within STRATCOM was a unique approach to accomplish the wide variety of missions assigned by the President. The first JFCCs were formed in January 2005 from within STRATCOM's resources. Each JFCC is commanded by a senior officer who is dual-hatted as the head of a complementary mission organization. The JFCCs are designed to be mutually interdependent and agile to deal with today's non-linear battlespace. As such, they operate in a distributed and collaborative fashion providing an integrated suite of operational capabilities. The basic concept of operations involves decentralizing operational planning and employment, leveraging authorities and capabilities in the complementary "dual-hat" organizations, and increasing operational speed.



Initially the USSTRATCOM structure included a JFCC for Space and Global Strike (SGS). General Cartwright tasked the commander of this JFCC with three very important missions—space, global strike, and integration across all the JFCCs. In this construct the commander of 14th Air Force was a subordinate, supporting commander to the commander, JFCC SGS. This arrangement placed a layer of command between the daily activities of the space mission (conducted by the Joint Space Operations Center) and Commander (CDR) USSTRATCOM, and added a mission to the already full plate of responsibilities for global strike and integration.

After one year of operations, CDRUSSTRATCOM and the





Chief of Staff of the Air Force determined that separating the space and global strike mission areas would better serve US national security interests. They agreed the best way to further integrate space across all USSTRATCOM mission areas would be to establish a stand-alone JFCC for Space. This new construct would also better align Air Force components to support USSTRATCOM, streamline the space operations chain of command, and allow the commander of JFCC Global Strike to focus on the critical strike and integration missions.

On 19 July 2006, General Cartwright restructured JFCC Space and Global Strike into two separate and distinct organizations: JFCC Space and JFCC Global Strike and Integration (GSI). This structure is intended to allow each JFCC to more effectively execute its primary mission and to support the warfighter with optimized planning, execution and force management for space and global strike operations. JFCC GSI is also responsible for integrating all elements of military power as it conducts, plans, and presents global strike effects.

Steps Forward

The JFCC SPACE is headquartered at Vandenberg AFB, California, and is commanded by Maj Gen William Shelton. The new construct is intended to strengthen space operations, improve responsiveness, and codify command and control of space forces. Elevating space as a stand-alone JFCC emphasizes the growing importance of space operations to our national security.

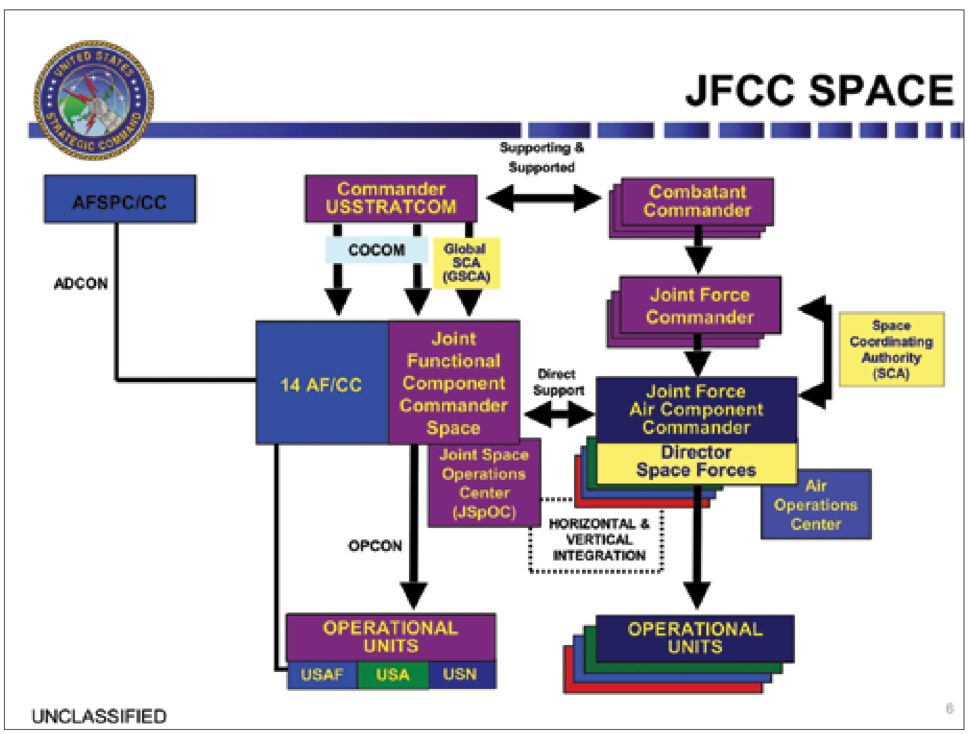
The new JFCC construct also complements the Air Force's plan to streamline presentation of its forces to each combatant command. In the Air Force's current construct, 14th Air Force would be the warfighting headquarters for space, AFSTRAT-SP, and 8th Air Force would be the warfighting headquarters for Global Strike, AFSTRAT-GS. In keeping with the other JFCCs, Major General Shelton is dual-hatted as the commander of 14th Air Force.

The JFCC SPACE concept as described in the Implementation Directive is as follows:

> "… the CDR JFCC SPACE will serve as the single point of contact for military space operational matters to plan, task, direct, and execute space operations … In close coordination with the headquarters staff, and JFCC GSI, JFCC SPACE will conduct space operational-level planning, integration, and coordination with other USSTRATCOM joint functional and service components, other Combatant Commanders [through their Space Coordinating Authority (SCA), and other [Department of Defense] DoD organizations, and when directed, non-DoD partners to ensure unity of effort in support of military, national security operations, and support to civil authorities."

Bringing Space To The Fight

The establishment of JFCC SPACE enhances unity of effort and unity of command for joint space operations. It also provides a joint focus for space operations and enhances joint and allied participation through the Joint Space Operations Center. Finally, this construct gives the combatant commanders a single point of contact for requesting space effects.



US Strategic Command Headquarters, General Curtis E. LeMay Building.

CDRUSSTRATCOM has delegated essential authorities to the CDR JFCC SPACE for operational and tactical-level planning, force execution, and day-to-day management of space forces assigned to STRATCOM. He has also delegated operational and/or tactical control of assigned forces to CDR JFCC SPACE along with granting direct liaison authority for working with the other combatant commands. Delegation of these authorities will enable an agile response, with desired space effects provided at the timing and tempo needed to support operational commanders across the globe.

We are also formalizing the relationships between JFCC SPACE and our interagency and commercial partners. Specifically, we are enhancing our operational relationship with the National Reconnaissance Office, National Geospatial Intelligence Agency, National Aeronautics and Space Administration, and the National Oceanographic and Atmospheric Agency. Strengthening these ties will enhance information sharing among the organizations and is expected to provide a more comprehensive decision-making process.

Future

In the future, we anticipate increased interaction and collaboration with our international mission partners and with the commercial space industry. Efforts to this effect are already underway among many different organizations. Similar to unifying space operations for the DoD, this unity of effort is being pursued across the US government. These improved relationships, using JFCC SPACE as the focal point for military space operations, will provide better employment for our limited space assets and will leverage complementary organizations in support of global and theater operations.

Lt Gen C. Robert "Bob" Kehler (BS, Education, Pennsylvania State University; MS, Public Administration, University of Oklahoma; MA, National Security and Strategic Studies, Naval War College) is Deputy Commander, United States Strategic Command, Offutt AFB, Nebraska. As second in command, he is charged with ensuring the command meets responsibilities for global command and control of strategic forces and remains ready to provide strategic assets to execute decisive national security objectives.

General Kehler entered the Air Force as a distinguished graduate of the Air Force ROTC program in 1975. General Kehler has commanded at the squadron, group and wing levels, and has a broad range of operational and command tours in ICBM operations, space launch, space operations, missile warning, and space control. He commanded a Minuteman ICBM squadron at Whiteman AFB, Missouri, and the Air Force's largest ICBM operations group at Malmstrom AFB, Montana. He served as Deputy Director of Operations, Air Force Space Command; and commanded both the 30th Space Wing at Vandenberg AFB, California, and the 21st Space Wing, Peterson AFB, Colorado.

The general's staff assignments include wing-level planning and tours with the Air Staff, Strategic Air Command headquarters and Air Force Space Command. He was also assigned to the Secretary of the Air Force's Office of Legislative Liaison, where he was the point man on Capitol Hill for matters regarding the president's ICBM Modernization Program. During an assignment to the Joint Staff, he helped formulate revolutionary changes to nuclear war plan structure and targeting. Most recently, as Director of the National Security Space Office, he integrated the activities of a number of space organizations on behalf of the Under Secretary of the Air Force and Director, National Reconnaissance Office. Prior to assuming his present position, he was the Director of National Security Space Integration in the Office of the Undersecretary of the Air Force, Washington, DC.

Small Satellite Multi-Mission Command and Control for Maximum Effect

Mr. Eric Miller
Manager Vandenberg Operations, General Dynamics
Lt Col Richard A. Lane, USAF
Director, Space Force Enhancement, AF Space Battlelab
Mr. Allen Kirkham, et al.
Military Analyst Space and Missile Defense Systems,
Army Space and Missile Defense Battle Lab

A great many advances have been made in small satellite technology in the past 10 years, but two associated elements continue to trouble the market: a ride to orbit and ground infrastructure to take advantage of the sensor platform. A great deal of effort has gone into the spacelift side with the emergence of new launch vehicles, with common spacecraft interfaces, to reduce the cost of getting to orbit. Flight interfaces have been developed out of necessity to limit the number of variables and allow both sides to build to a common interface. The same has not been true for the ground operations infrastructure. With notably few exceptions, space platform architectures are paired with mission specific ground infrastructures designed to optimize the interface. These stovepipes ensure an efficient tie within a system, but don't allow for ready use outside of the stovepipe. In essence current ground infrastructures are not readily adaptable to a new mix of space-based sensor platforms, and the small-sat providers find themselves looking for a customer who is willing to invest in a ground station as well as the sensor platform.

Improvements are needed at both ends of the ground infrastructure: the spacecraft ground station operator and the deployed operational or tactical user. Current use of network interfaces for the Joint Space Tasking Order (JSTO) process is limited to email and text messaging to relay requirements to and from the field. Often the status of an on-orbit asset is inferred by manually reviewing mission logs to identify why a specific task was not accomplished. Currently, the Joint Space Operations Center (JSpOC) manually derives detailed status of mission assets, such as constellation health, current tasking levels, ground station availability, and impacts due to future operations. These details are obtained from a variety of systems, in several formats, with no common way to access the required information.

Space operations need robust tools that can track current conditions, receive real-time requests from the field, predict future mission capabilities, correct for limitations, and automate information flow that does not rely on hand entry or delving into mission logs for status. Often JSTOs are generated without knowing the true status of the assets and whether or not the operations will deliver the required effects to the theater. In addition, the Joint Warfighting Space (JWS), near-space, and tactical satellite (TacSat) programs are attempting to fly new sensor technologies that advance operationally responsive space (ORS).

Global Apportionment

As the sensors and platforms are coming out of the research and development environment, the missions tend to have a multitude of agencies involved. When the sensor platform is delivered and placed into operation, the mission lacks a single operations manager needed to obtain the maximum benefit and to ensure that the new technology is being evaluated within the operational environment it is expected to support in the future.

On 19 July 2006, United States Strategic Command (USSTRATCOM) created a joint functional component command for space (JFCCSPACE) at Vandenberg AFB, California. The Commander (CDR) JFCCSPACE is the primary USSTRATCOM interface for joint space effects to the supported commander. The CDRJFCCSPACE exercises operational control (OPCON) or tactical control (TACON) of designated space forces through the (JSpOC). This 24/7 node executes CDRJFCCSPACE missions for joint space command and control. CDRJFCCSPACE is the global space coordinating authority; the single authority in USSTRATCOM to coordinate global space operations and integrate space capabilities CDRUSSTRATCOM does not control. The processes within the JSpOC are based on those used within an air operations center.

The tasking of all US space assets OPCON or TACON to CDRJFCCSPACE begins with the JSpOC Strategy Division, collecting the intent and needs of CDRUSSTRATCOM, CDRJFCCSPACE, all theatre space coordinating authorities (TSCA) and all supported commanders. These requirements are prioritized and a space operations directive is produced listing the effects required during a 24-hour period. These prioritized effects are then balanced against available resources in a joint master space plan that forms the basis for a JSTO. The

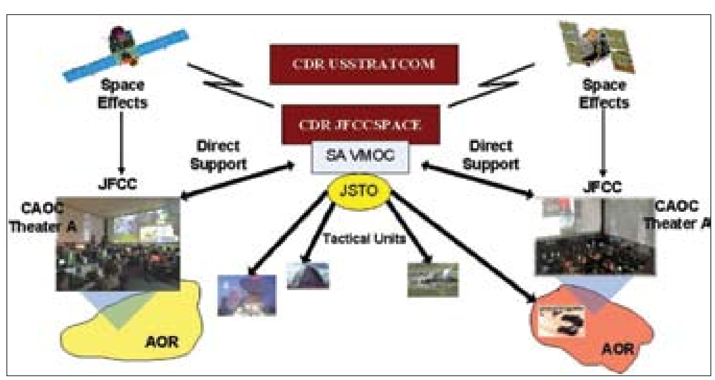


Figure 1. Balanced Space Effects.

JSTO is passed to subordinate units who then have 12 hours to plan how to deliver the effects required and 24 hours to deliver those effects.

This process has a number of difficulties as it stands. First, it can not easily be shortened to be more responsive to warfighters' needs. In the air, land and maritime worlds, recent operations have driven home the recognition that some targets are time sensitive and require effects on target within the normal tasking cycles. Similarly, some space effects are needed within shorter time-scales than the normal process allows; currently these effects are directed by issuing changes to the JSTO. Secondly, the single JFCCSPACE can not synchronize its battle rhythm with each and every TSCA and supported commander. TSCA battle rhythms tend to be based on the local time in that theatre. If the JFCCSPACE battle rhythm happens to coincide with that of a particular TSCA, it will certainly not coincide with other TSCA's rhythms. Finally, existing processes can not direct effects in the timescale that ORS sensor platforms such as TacSat and JWS will require. A TSCA that has been apportioned an ORS asset launched to support that specific theatre will demand effects in real-time—not tomorrow.

It is clear, therefore, that it is necessary to develop a means to rapidly collate required effects worldwide, prioritize these effects and then deliver them. The JSpOC is the appropriate organization for managing the global apportionment of space assets for theater effect, but will require a new set of tools. By integrating key network-centric elements of the Virtual Mission Operations Center (VMOC), the JSpOC can begin to model and effectively apportion global platforms and sensors for maximum theater effect. With this in mind, the AF Space Battlelab and General Dynamics proposed the Space Apportionment For Effect (SAFE) demonstration that provides the JSpOC the relevant environment needed to frame the network-centric, automated, end-to-end requirements flow needed to bound the JSTO tactics, techniques, and procedures (TTPS) required to maximize theater space effects.

SAFE Demonstration

The Air Force Space Battlelab's 2006 SAFE initiative will demonstrate space apportionment and VMOCs in a "Systems of Systems" environment. SAFE will be accessed by the JSpOC, combined air operations center (CAOC), satellite operations center (SOC), and field deployed users to begin developing the concept of operations that will support ORS deployment. The demonstration provides the CAOC direct access to sensor platforms and data that have been apportioned to them by the JSpOC. The VMOC tools will enable the JSpOC to model heritage and TacSat assets, fly the mission virtually in future time to refine the operations and iterate to obtain the optimum theater effect, generate an automated JSTO, and issue the JSTO to the SOC for implementation—all through a standard secure web environment. As shown in figure 2.

In-theater operations support requests will be made via VMOC web pages in the test CAOCs representing multiple theaters. CAOC-Experimental at Langley AFB, Virginia, will serve as the test CAOC for the demonstration. Within each

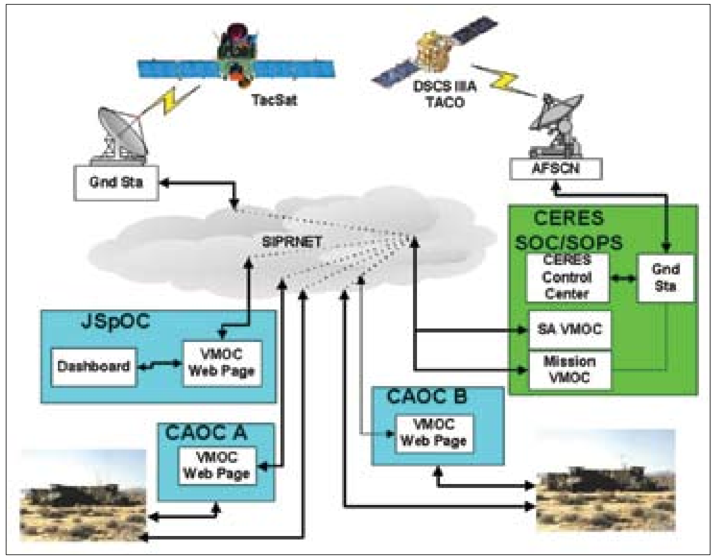


Figure 2. Space Apportionment For Effect (SAFE).

theater, the Director of Space Forces (DIRSPACEFOR) will have access to the JSpOC and VMOCs, and through them, will be able to allocate apportioned space effects to the warfighters within the theater.

As an example, the JSpOC receives a request from Theater A for space-based imagery in support of an Army-deployed unit and a simultaneous request from the Theater B CAOC for space-based imagery and communications support for another deployed unit. The JSpOC will attempt to support operations in both theaters handling conflicting requirements for limited resources. Once the JSTO is issued, the VMOC will be updated automatically to provide the theater warfighter direct access to the apportioned sensor platform and required data as directed by JSpOC policy. The JSpOC will use the situational awareness VMOC tools to optimize the effects to both theaters. Upon review and approval by the JSpOC, the system will automatically generate and release the JSTO to the VMOC and Air Force Space and Missile Systems Center (SMC) Det 12/CERES as the Space Operations Squadron assigned to 14 AF. Real-time telemetry will be monitored by the VMOC and status will be displayed on the dashboard for the JSpOC and CAOC. Additionally, when the JSpOC issues the JSTO, the user permissions are automatically updated in the VMOC to allow the CAOC to manage the direct support given to the Army deployed unit. The JSpOC provides management of the space assets for the mission by prioritizing the allocation of resources between the two theaters. Theater-level management is performed by the CAOC DIRSPACEFOR through appropriate VMOC user privileges. The DIRSPACEFOR apportions the access, allotted by the 14 AF, as required to meet in-theater objectives.

The SAFE demonstration is designed to follow the standard command and control procedures in place today. The fundamental difference is that it is automated, reacting to changing environments, with situational awareness given via the dashboard that provides elements of a single integrated space picture. All members of the management chain will have insight into the resource allocation and apportionment, the health and status of the constellation, and the level of support being pro-

vided to the warfighters in the theater. Over the course of the demonstration, multiple scenarios will be tested, including sensor platform subsystem outages, ground station failures, and real-time reapportionment of assets.

While the SAFE demonstration focuses on the automated JSTO and interaction with the theater users, it does not address the need for a field deployed ground station that provides the theater direct down link needed to maximize space-based effects. This aspect is covered by the Army multi-use ground station (MUGS) demonstration.

MUGS Demonstration

The Army Space and Missile Defense Battle Lab's (SMDBL) MUGS Spiral 2 provides the framework to demonstrate network-centric telemetry, tracking, and command (TT&C) and develop TTPs for command and control of tactical space assets. The MUGS experiment demonstrates the ability for anyone with secure Internet/Intranet access, and authority, to directly task a low Earth orbit (LEO) or near-space sensor platform and payload from the theater, retrieve the data, and post the data on a net-centric server for retrieval by the requester. Net-centric tasking and apportionment by a theater commander's collection manager will be critical for theater operation of TacSats and near-space assets of the future.

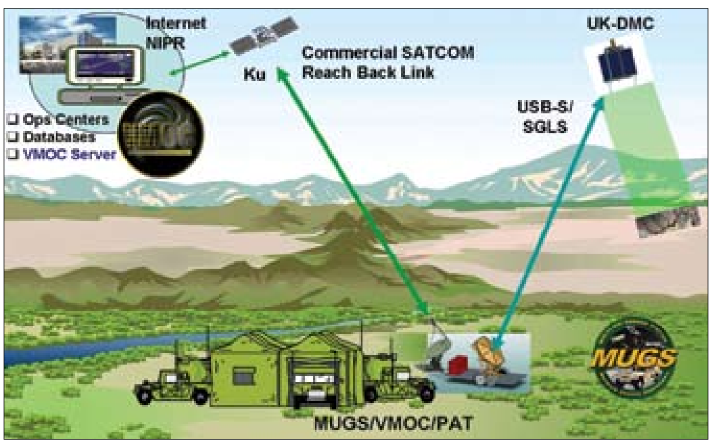


Figure 3. Multi-use Ground Station Overview.

To best simulate the relevant tactical environment (figure 3), MUGS combined the General Dynamics' VMOC and the SMC S-band phased array for telemetry, tracking, and commanding (PAT) to provide theater direct up and down link with the Surrey Space Technologies Ltd (SSTL) United Kingdom-Disaster Monitoring Constellation (UK-DMC) satellite.

For the demonstration, the VMOC is located at National Aeronautics and Space Administration Glenn Research Center (NASA GRC) in Cleveland, Ohio and is connected to the Army demonstration location in Colorado Springs, Colorado via the open Internet. In addition, the VMOC is connected to the SSTL ground station in Surrey, UK. The demo concept of operations takes advantage of having two ground stations to maximize connectivity with the space asset. When a field user requests an image, the VMOC determines the optimal configuration to return the image by the most effective path.

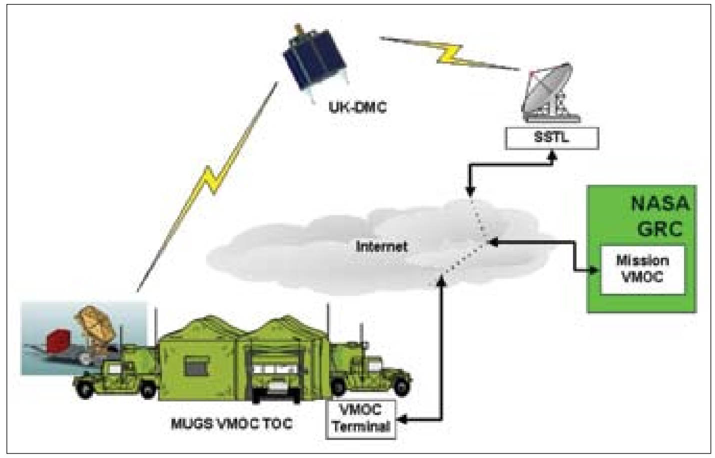


Figure 4. Net-centric Connectivity.

The prioritized SMDBL MUGS demonstration scenarios include:

1. Task the UK-DMC from MUGS and receive the image from MUGS.
2. Task the UK-DMC from MUGS and receive the image from the SSTL ground station.
3. Task the UK-DMC from the SSTL ground station and receive the image via MUGS.
4. Task the UK-DMC from the SSTL ground station and receive the image from the same ground station.

A point of concern with a demonstration that utilizes an operational resource, is scheduling. To ensure the demonstration does not disrupt the UK-DMC operations, a single scheduler will be used. In this case the VMOC will tie to the SSTL Mission Planning System for all user requests. Regardless of the path the request is filled by, all the imagery will be stored on both the VMOC and the SSTL databases.

The MUGS demonstration lays the foundation for a net-centric field deployed ground station required to support ORS.

General Dynamics' Virtual Mission Operations Center

General Dynamics' VMOC is a web-based architecture designed for a network-centric environment that:

- Adjudicates networked exchanges
- Centralizes control authority policy
- Decentralizes execution
- Uses thin and thick client web interfaces

The VMOC provides a framework to define, test, demonstrate, and field new technologies within the relevant environment capable of supporting secure distributed mission operations of heritage and internet protocol-based platforms and sensors. The VMOC's rules-based authentication, modeling, multi-mission planning, scheduling, and TT&C gives command authorities, analysts, operators, and users unparalleled tools for controlling complex platforms to maximize mission effectiveness.

The SAFE and MUGS demonstrations are follow-ons to the successful 2004 VMOC demonstration that was a joint effort among the AF Space Battlelab, Army SMBDL, NASA GRC,

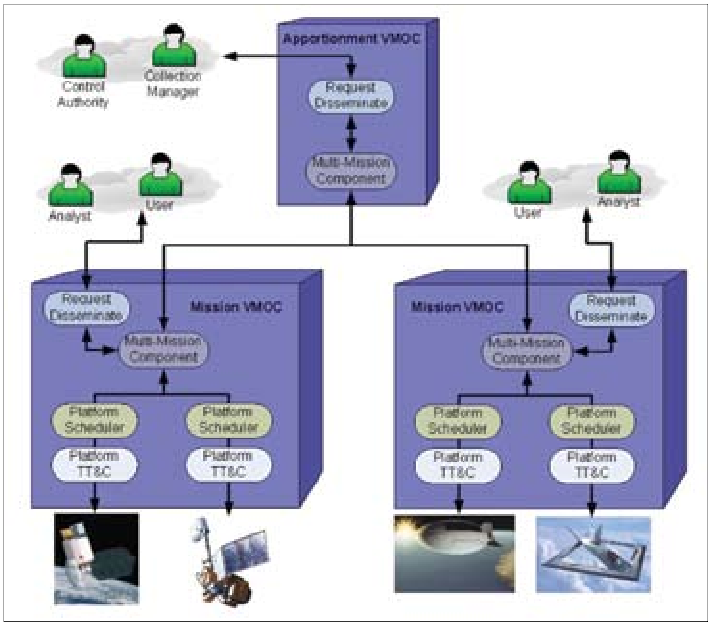


Figure 5. Global Apportionment, Theater Execution.

Naval Research Laboratory (NRL), and General Dynamics that validated the capability to use secure Internet protocols to perform TT&C as well as payload tasking of on-orbit assets.

VMOC development to date has focused on asset apportionment and mission operations. As shown in figure 5, the apportionment VMOC ensures the right person has access to the right asset as priorities and mission needs change by rapidly changing the mission rules sets that dictate access to the VMOC. The VMOC is the user's direct interface with the sensor platform. If a platform sensor has be apportioned to a set of users, all priority and scheduling is handled within the VMOC to ensure access follows control authority policy. If a user requests an effect that is out of scope to the current apportionment, the control authority is notified of the new requirement. If the request is validated, a new mission rule set is sent to the VMOC. Interaction between users and the VMOCs is by simple web browser. No mission specific software is required to reside on the user's computer.

Integration of key technologies and architectures like VMOC, are creating a decisive warfighting advantage for tomorrow's battlefield.

United States Naval Research Laboratory VMOC Spydr

The NRL VMOC Spydr is a net-centric test bed that explores advances in multi-tiered systems through continuous operational experimentation.[1] Developed consistent with FORCEnet principles, it aims to pair and co-evolve the latest web technologies with the latest concepts of operations. The impetus for the VMOC Spydr began with the need to task and retrieve sensor data from TacSat-1. TacSat-1 is a LEO micro-satellite developed by the NRL in response to a need for quick and inexpensive satellites that can serve as sensor gap fillers for operational military commands. VMOC Spydr has matured and is now able to receive data from various sensors, making it a versatile and flexible net-centric information management system. Unlike massive databases, the VMOC Spydr does not host nor maintain large volumes of sensor data. Instead, sensor nodes (e.g., TacSat-1) collect and store data to local data servers called sensor concentrators (SC). The SC perform such tasks as sensor scheduling, data processing, and data feed generation. The data feed generated by the SC is sent to the VMOC Spydr using existing extensible markup language standards ("Atom" feeds) via open web services. This data feed describes the data contents and its corresponding meta-data. The VMOC Spydr catalogues the various feeds it receives and alerts subscribers of new data. This scalable approach allows a broad user base to access, collaborate, and disseminate data collected from multiple sensors seamlessly. The overall intent is to create an environment that enables user collaboration in order to increase individual and shared situational awareness across organizational lines. Figure 6 depicts the architecture.

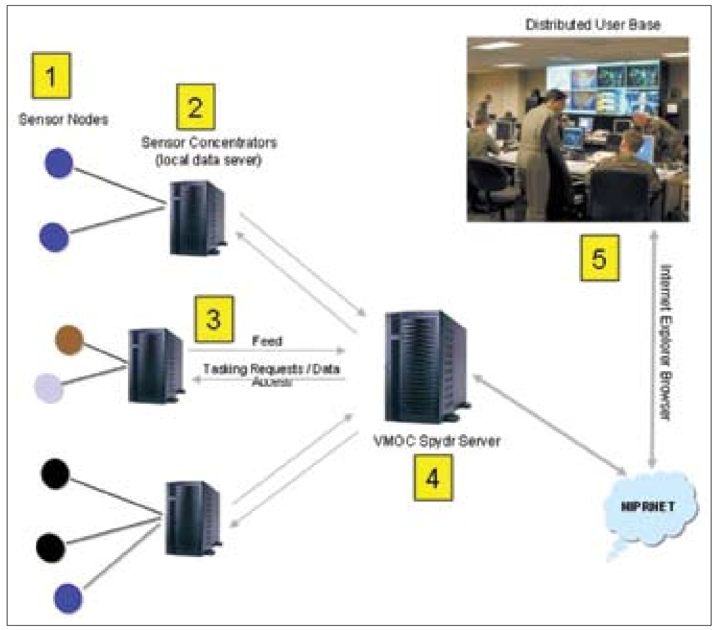


Figure 6. VMOC Spydr Multi-tiered System Architecture.

The desired effect of this broad based collaboration via this architecture is to increase shared situational awareness amongst disparate and geographically dispersed groups.

Figure 7 depicts the process from data collection to action required to achieve this effect. The backbone of the architecture is based on Dr. Micah Endsley's work on situational awareness. The first level is awareness of the environment or battlespace. This is achieved through various tool sets that collect, process, validate, disseminate, alert, and grant users access to data. A good example is the General Dynamics' VMOC serving as the sensor concentrator for the VMOC Spydr. To the users, these systems create an individual mental model of the environment or battlespace. Without the proper tools in place to share individual mental models, errors in communication may lead to incorrect action. The second level of situational awareness, as depicted in figure 7, aims to share mental models in order to create a common comprehension between players. Within the

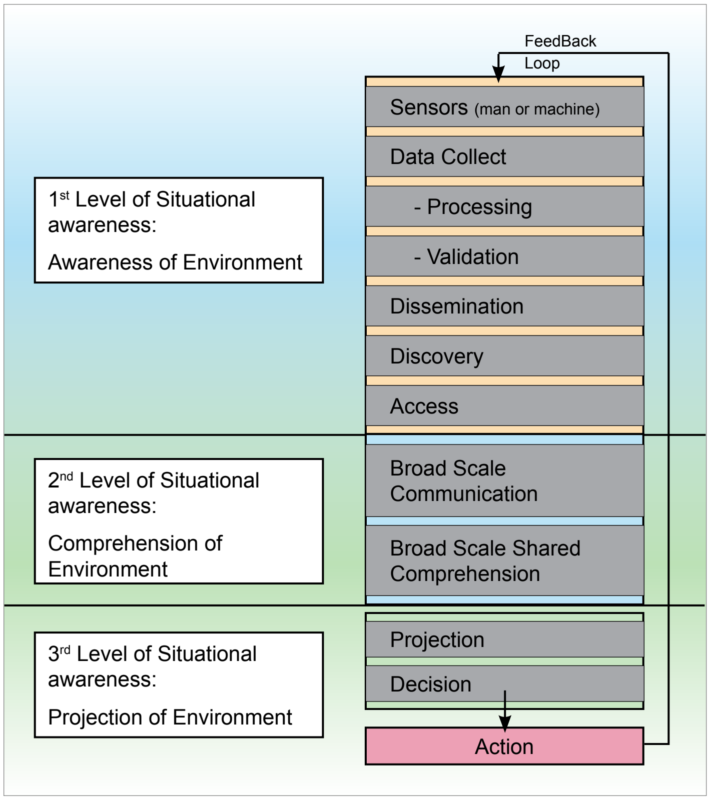


Figure 7. Processes for Achieving Action.

VMOC Spydr design there is a heavy emphasis on collaborative tools such as chat, forums, and image annotation that help achieve this level of situational awareness. The third level is projection and decision. After the environment is surveyed and evaluated, and a shared comprehension exists, members of a group can project cause and effect relationships with various courses of action. The last step is action based on decisions. In concept, the VMOC Spydr web site, not including the various SC, is situated between data dissemination and broad scale comprehension.

VMOC Spydr is being developed by the NRL with support from the Office of the Secretary of Defense's, Office of Force Transformation (OFT) via a campaign of operational experiments. Operational experimentation aims to meet the immediate and emerging needs of warfighters by rapidly progressing through the design, build, test, and deploy cycle. Through these cycles, the VMOC has emerged as a test bed to explore and validate the various interfaces that are required to create the architecture in figure 6. It is also the platform with which to conduct operational experimentation in order to determine the changes in mission performance due to the framework in figure 7. To date, OSD/OFT has integrated the VMOC Spydr in several exercises with Department of Defense (DoD) and non-DoD players. In these exercises, data from various sensors were used to evaluate the functionality and utility of the web site, as well as to mature emerging concepts of operations. The VMOC Spydr architecture and design are continually being matured and through operational experiments and system improvements will new concepts of operations be enabled via the latest technologies.

National Aeronautics and Space Administration Internet Protocol version 6 Demonstration

In September of 2003, John Stenbit, DoD Chief Information Officer, signed a policy memorandum that outlines DoD's transition from Internet Protocol version 4 (IPv4) to Internet Protocol version 6 (IPv6) by 2008 as IPv4 is considered inadequate and incapable of meeting the long-term requirements of commercial DoD and entities. The achievement of net-centric operations, envisioned as a Global Information Grid of interconnected sensors and systems, depends on the effective implementation of IPv6. The DoD goal is to complete the transition to IPv6 for all inter- and intra-networking across the DoD by fiscal year 2008. Recently, the US government has mandated a similar transition for all US federal government agencies including NASA. Budgetary realities have moved these dates out a few years. Nonetheless, the transition is taking place.

Some of the advantages that IPv6 has over IPv4 include:

- A sufficiently large address space to provide globally unique addressing
- Return of the end-to-end principles of the Internet (no need for network address translation)
- Auto configuration
- Improved security provided by
  - Scoped addressing
  - IP security capability as part of the protocol
  - No fragmentation
  - Multicasting instead of broadcasting

On 27 September 2003, a Cisco Systems router (Cisco in low Earth orbit [CLEO]), was launched onboard the UK-DMC disaster-monitoring satellite built by Surrey Satellite Technology Ltd. (SSTL). The router was used to demonstrate net-centric operations in June 2004 using IPv4 normal and mobile routing.[2] The router firmware also included IPv6 routing although it does not poses IPv6 Internet Protocol Security (IPsec) capability or network mobility code as neither technology was available at the time of launch to orbit. For the next demonstration, the IPv6 capabilities will be enabled and the necessary ground networks will be configured to demonstrate IPv6 connectivity to a space-based asset. Static IPv6 routing will be used as will IPv4/IPv6 transition mechanisms.

In the 2004 VMOC/CLEO demonstration, mobile networking to the satellite from a secure infrastructure was demonstrated using IPv4. A number of ground stations where used for that demonstration including an SSTL ground station in Guildford, England, an Alaska ground station owned and operated by Universal Space Network Inc. (USN), and a receive-only ground station operated by the US Army SMDBL. The upcoming NASA IPv6 demonstration plans to use the SSTL and MUGS ground stations, the enhanced DMC interface developed by USN under a US Air Force contract, and an S-band ground station owned and operated by the Hiroshima Institute of Technology.

NASA will use most of the original network put in place for June 2004 VMOC/CLEO demonstration. Initially, the mobile network IPv4 'home-agent' router will serve as the anchor point or "anchor router" for all IPv6 communications. Static

host routes will reside in the anchor router. The CLEO will be enabled for IPv6 and multiple host addresses will be configured, with each host route corresponding to a different ground station. In this manner, one can implement a predictive routing mechanism such that a controller can intelligently predict which ground station will be in contact with CLEO and transmit data to CLEO via that particular, unique host address as shown in figure 8.

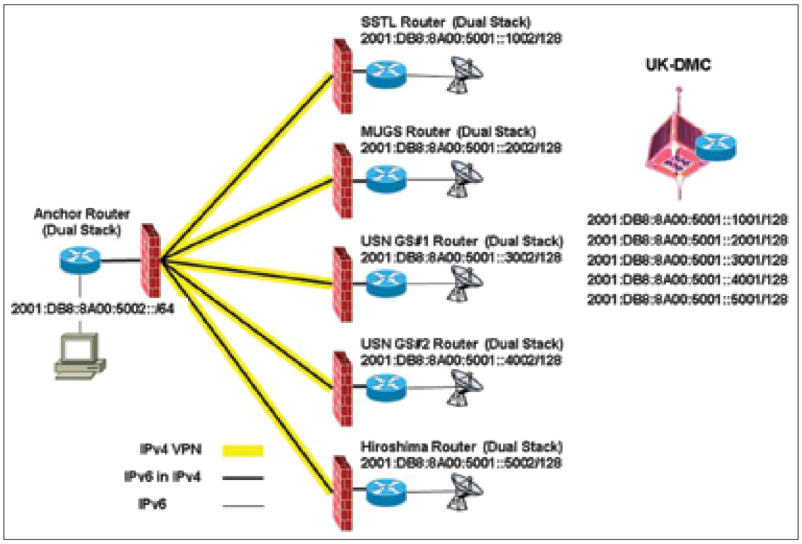


Figure 8. Predictive Ground Station Routing.

Since SSTL's ground infrastructure is an operational system, the team plans the first deployment and test of IPv6 using the MUGS demonstration capability. Once configurations are proven with MUGS, they can be ported to the SSTL operational terminal as well as others.

Besides static IPv6 routing, NASA plans to encapsulate IPv6 packets inside an IPv4 IPsec tunnel thereby demonstrating network layer security from space to ground. In addition, NASA may attempt to run IPv6 over IPv4 mobile networks.

United States Geological Survey Demonstration

The risk of natural and man-made disasters on a national and global basis are ever increasing. Thus, there becomes a growing need to not only maintain our existing capability, but, more importantly, also expand and improve our coordination and infrastructure to support research, hazards monitoring risk assessment and management, and communication activities worldwide.

The United States Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) serves as a central coordination point for the acquisition and dissemination of remote sensing data in response to natural and man-made disasters in the US and abroad. USGS EROS designation as the National Satellite Land Remote Sensing Data Archive for remotely sensed (satellite and aerial) data, enables the provision of historical and pre-event data for disaster response activities. Working with federal agencies such as US Department of Homeland Security, US Federal Emergency Management Agency, and US Northern Command, as well as state and local government agencies, EROS's emergency response team also coordinates the collection and scheduling of new acquisitions during disaster response operations.

The USGS is a partner agency in the International Charter on Space and Major Disasters, which represents a joint effort by global space agencies to put resources at the service of rescue authorities responding to major natural or man-made disasters.

The charter is based on voluntary contributions, by all parties, of Earth observation satellite data. Each member agency has demonstrated its commitment to using space technology to serve humankind when it is most in need of assistance, in case of natural or technological disaster with data providing a basis for anticipating and managing potential or actual crisis. Announced at UNISPACE III conference held in Vienna, Austria in July 1999, the charter was initiated by European Space Agency and French Space Agency (Centre National d'Etudes Spatiales) with the Canadian Space Agency. Other partners include the Indian Space Research Organization, the US National Oceanic and Atmospheric Administration, USGS, the Argentine Space Agency, the Japan Aerospace Agency, UK-DMC, with the United Nations as a cooperating body.

Since November 2000, the International Charter on Space and Major Disasters has been activated more than 100 times to assist in emergencies such as floods, fires, landslides, typhoons, volcanic eruptions, oil spills, tsunamis, hurricanes,

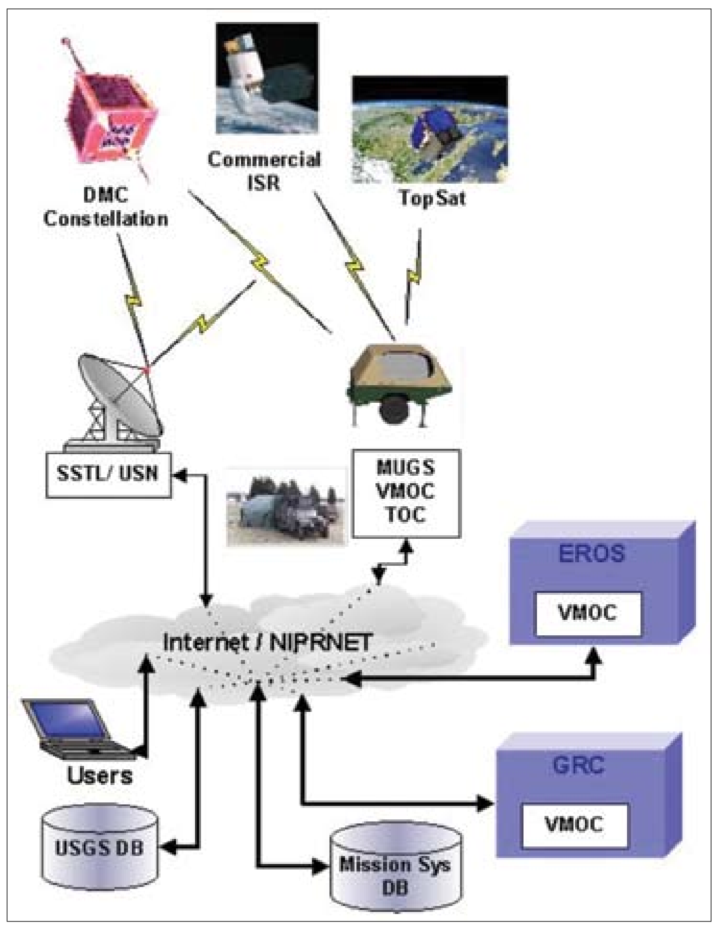


Figure 9. EROS Disaster Response.

earthquakes, and civil accidents which occurred all around the globe. With a low response of 38 to 48 hours and by facilitating high reliability data, the charter proved the effectiveness of space information for emergency management. The charter and its partner agencies played a major role in supporting two of the largest disasters in recent times, the 2004 tsunami and Hurricane Katrina.

Teaming with the US Air Force and US Army, USGS EROS will demonstrate how the VMOC can provide space-based assets in support of disaster response. The intent is to demonstrate how: (1) the aggregated access to additional archives and payloads, (2) the capability to task and schedule collections based on changing priorities, and (3) comprehensive views of asset capabilities will provide EROS emergency response personnel with significantly improved resources supporting their image acquisition missions both nationally and with the International Charter on Space and Major Disasters. The VMOC will be used to view all available assets for an event on a daily basis and will allow tasking and scheduling to proceed with maximum speed and minimum redundancy.

During disasters the loss of communications infrastructure can make data delivery very challenging. With the loss of Internet capabilities, using media such as CD, DVD, and firewire becomes a necessity. The MUGS framework will be used to demonstrate how it will be possible to maintain communications with the field, assuring there is no loss of direct downlink from the space sensor platform. The MUGS will be used to maintain field user interfaces and provide for the delivery of any remotely sensed data acquired during the exercise.

The USGS EROS emergency response program plans to demonstrate that through the use of the VMOC and MUGS, we will be able to provide disaster response remote sensing products in a timely and proactive fashion by making the data easily and rapidly accessible to the response community.

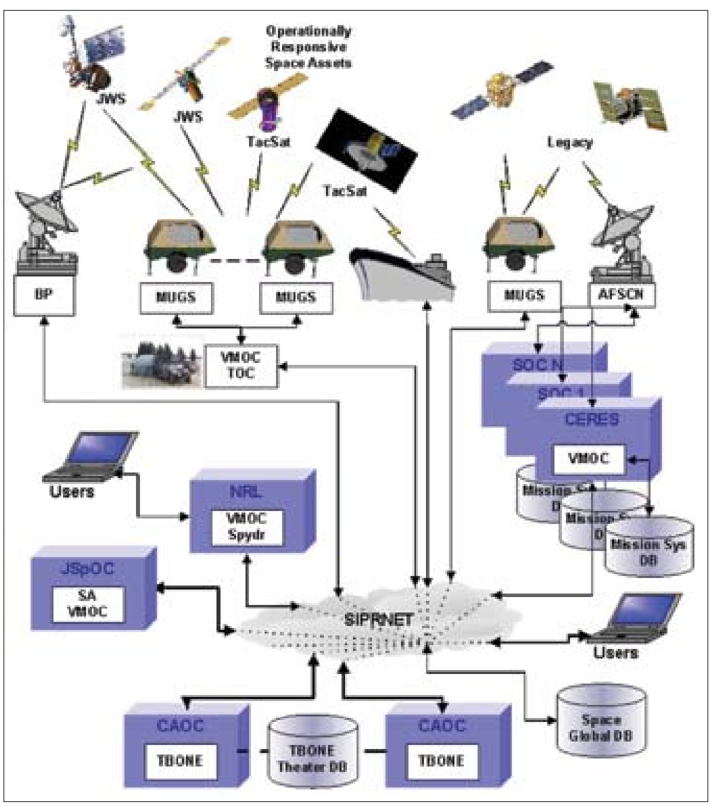


Figure 10. Responsive Space Operations.

Way Ahead

The demonstrations and experiments discussed in this paper will allow operators to examine concept of operations and help determine their future system requirements. Current systems are working but the capabilities are limited and largely stovepiped. Future systems, such as responsive space assets (TacSats and near-space), will dramatically stress current system capabilities and will require automated machine-to-machine tools for global apportionment, optimized for theater operations. Will the initiatives discussed in this paper fulfill 100 percent of the operator's needs? Most likely not—but what they can do is allow operators and warfighters to examine what works and what doesn't. Using common interfaces and net-centric software, these "systems of systems" can be more easily interfaced and adapted to provide the responsive space architecture notionally shown in figure 10.

Summary

The collaborative VMOC demonstrations create the relevant environment needed to frame the network-centric, automated, end-to-end requirements flow that enhance space effects to the users. Small teams, working together for an optimum solution, can use a spiral development approach, adding capabilities to enhance operations. These initiatives are inherently easy to expand among government and commercial agencies. Programs, such as VMOC, SAFE, MUGS, IPv6, and Spydr, will undoubtedly lay the groundwork for the fundamental change needed to move toward net-centric satellite operations.

Notes:

[1] The term *Spydr* is a play on the word spider. It is intended to convey the ability to navigate like a spider across the web in order to pull data and users together and form communities of interest regardless of organizational boundaries

[2] W. Ivancic, P. Paulsen, D. Stewart, D. Shell, L. Wood, C. Jackson, D. Hodgson, J. Northam, N. Bean, E. Miller, M. Graves, and L. Kurisaki, Secure, network-centric operations of a space-based asset: Cisco router in low Earth orbit (CLEO) and Virtual Mission Operations Center (VMOC), NASA Technical Memorandum TM-2005-213556, May 2005.

Additional Authors:

Mr. Omar Medina
Virtual Mission Operations Center
Spyder Program Manager,
US Naval Research Laboratory

Mr. Will Ivancic
Project Engineer, NASA Glenn Reseaarch Center

Ms. Brenda Jones
Disaster Response Coordinator,
Science Applications International Corporation

Mr. Ron Risty
Disaster Response Coordinator,
Science Applications International Corporation

Space Professional Update

Space Professional Education: The Next Step Through Continued Education

Maj Marc Peterson, USAF
Chief, Bases and Units Branch, AFSPC/A8IB

Rather than take up valuable space unnecessarily proving a point, this article makes the assumption continuing education for the credentialed space professional is important. Furthermore, this article asserts the possibility of creating more effective space professionals in Air Force Space Command (AFSPC) through the use of hands-on learning techniques. If officers can be made more effective through the use of more effective teaching methods, then it seems reasonable to pursue that course of action.

Red Flag

The introduction of Red Flag into this effort serves the purpose of understanding the benefit of realistic training and education outside of combat. In other words, Red Flag showcased the importance of practical application of studied theories. It also provided an excellent example of the bold decisions made by senior leaders in the face of adversity. It is the position of this article that scenario-based course of action development in the work centers provide similar benefits in the educational arena as those gained in Red Flag. The uninformed reader might attribute the success of Red Flag to a brilliant idea that simply made sense, and whose time had come. To better understand the magnitude of starting Red Flag one must understand the environment that existed at the time of the decision. The 12th Chief of Staff, General Larry D. Welch, USAF, retired, described the era and actions of the then Tactical Air Command commander, General Robert J. Dixon, USAF, retired, as having "the task of the most extensive [combat aircraft] conversion in modern times. He had to do it in a Cold War environment that demanded that we maintain our full commitment to North Atlantic Treaty Organization. He had to do it with absolute minimum resources and he had to support meeting the same challenges in Europe and the Pacific. That was an incredibly complex set of tasks. I have characterized the demand as changing your shirt without taking off your jacket."[1]

General Dixon was faced with a daunting task, and the fiscal constraints of a post-Vietnam military force in the throes of downsizing. In the midst of these challenges General Dixon remained receptive and immediately sought to implement the concept of Red Flag in spite of the fiscally constrained environment. Maj Gen George A. Edwards, Jr. stated, "It should be also noted that, from the outset, funds for Red Flag were taken out of the TAC hide until money could be obtained through the normal funding process.

General Dixon also found the funds to establish other 'Flag' programs for realistic training in other functional areas."[2] The lessons of Red Flag remain as applicable today as they were then. More effective Airmen contribute to mission success. It is my belief that the practical application of theory is equally capable of improving the effectiveness of students in the classroom, and space professionals in their work centers as it is at improving survival rates of combat pilots.

Educational Trends, The Art of Instruction

"Most ideas about teaching are not new, but not everyone knows the old ideas." - Euclid, c. 300 BC

The Air Force values educated Airmen, and has researched and published volumes of information regarding the education of students. An understanding of the advantages and disadvantages of different methods of instruction provides the framework required to realize the benefits of increasing the use of practical application scenarios in continued education. The Air Force recently published 461 pages entitled Air Force Manual 36-2236, Guidebook for Air Force Instructors, in an effort to provide a fresh rethinking of a complex and not completely understood subject—how to teach in the academic classroom so Air Force people will be more effective on the job.[3] The first chapter states, "Students need the opportunity to try what has been taught. Too often, instruction is limited to the delivery of information, either through reading assignments, lectures, films, or type 0 and type 1 computer-based training. Academic instruction should allow adult learners to practice what has been taught, receive feedback on their performance, and incorporate improvement as they move on to new material."[4] This being the case then the question to ask is what would be the most effective method of instruction to enhance continued education of the space professional.

Traditionally, lecturing has been the most popular teaching method in the military.[5] Unfortunately, the lecture method also has its share of critics. Dr. Richard M. Felder, codirector of the National Effective Teaching Institute (NETI), and Hoechst Celanese Professor Emeritus of Chemical Engineering at North Carolina State University, proposes learning by doing and in his article he wrote, "Thanks to some excellent classroom and cognitive research in recent decades, we know a great deal about how learning happens and how little of it happens in lectures."[6] He goes on to write, "There's no mistaking the catatonia that falls over classrooms after even just a few minutes of it. Numbed minds can't learn."[7] Some may discount the negative impression of lectures presented by Dr. Felder, and attribute his example to a poor instructor. However, Dr. Felder's description of lectures may be closer to the truth than one may be comfortable admitting. If our beloved lecture is not the most effective method for continued education then what method is the most effective?

One of the first steps in determining the most effective meth-

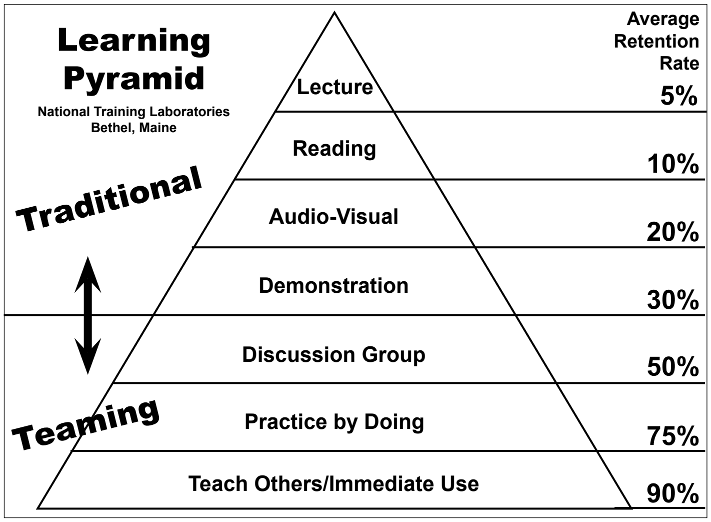


Figure 1. Learning Pyramid.

od of teaching is to determine how important the information is to remember. As basic as this statement may seem the results may astound you.

Retention Rates

The National Training Laboratories in Bethel, Maine developed a model entitled the "Learning Pyramid." (figure 1) The Learning Pyramid was designed to identify student retention rates with various types of instruction. The types of instruction covered in the pyramid include lecture, reading, audio-visual, demonstration, discussion group, practice by doing, and teach others/immediate use. The model identifies traditional approaches to learning along with their retention rates as well as modern, teaming approaches, and their retention rates.

Traditional approaches to learning include lecture, reading, audio-visual, and demonstration. The lecture method of learning generated a 5 percent average retention rate, and so forth, the method having the worst rate of retention. Learning through reading produced a slight increase, but only achieved a retention rate of 10 percent. Herein lies the crux of the matter.

Air Education and Training Command (AETC) and National Security Space Institute (NSSI) curriculum rely heavily on the traditional methods of learning through lecture and reading. Air Force manuals provide insight into the low-retention rates by stating, "Too often, the lecture makes no provision for student participation. As a result, many students willingly allow the instructor to do all the work. Learning is an active process—the lecture method, however, tends to foster passiveness and dependence on the instructor."[8] The teaming approach to learning provided more promising results. Methods of instruction associated with the teaming approach include discussion groups, practice-by-doing, and teaching others. The teaming approach to learning generated much higher retention rates than the traditional approach because teaming involves the student in an active process.

Understanding retention rates allows one to consider areas where the greatest improvement can be found in generating more effective space professionals in AFSPC. The most effective lecturer, on average, can produce a 5 percent retention rate at best. Therefore, it seems logical that improvement efforts would bear more fruit through focused attention to the method of instruction rather than on the instructors themselves.

Research shows that higher learning is an interactive process that results in meaningful, long lasting changes in knowledge, attitudes, values, and skills. The Air Force position to teaching states, "the only acceptable evidence that successful teaching has taken place comes from indications of change in student behavior."[9] Active or "cooperative" learning is the instructional use of small groups so that learners work together to maximize their own and each others learning.

Creativity

"Air Force instructors, then, should be creative instructors, who know when to be guided by time-tested methods and when to strike out boldly in new directions." - AFMAN36-2236

A creative departure from more traditional approaches includes more participatory methods of instruction like case studies, guided discussion and gaming to name a few. Case studies require student participation when presented with real-life situations in a classroom environment. The student can determine various approaches to realistic situations through the application of previously learned concepts. The "Learning Pyramid" identifies discussion groups as the first level of the "Teaming" approach to teaching and rated this method at 50 percent average retention rate. The guided discussion is especially effective at presenting material where experts on the subject do not always agree. "The discussion method is a superior method for teaching more complex cognitive and affective objectives. Thus, this method is appropriate for promoting the understanding of concepts and principles and for the development of problem-solving skills."[10] Now that we have identified discussion groups and practice-by-doing methods could be a more effective approach for continuing education it begs the question of what should be discussed or practiced.

Recommendation

"One can afterall, not condemn a method without being able to suggest a better alternative." - Carl von Clausewitz

Now, more than ever, US military leaders must develop their ability to think critically. Historically, militaries, their leadership, equipment, and training were prepared to fight the last

"The discussion method is a superior method for teaching more complex cognitive and affective objectives. Thus, this method is appropriate for promoting the understanding of concepts and principles and for the development of problem-solving skills." - AFMAN 36-2236

war. Developing the type of forces and equipment for the conflict of the future along with appropriate tactics, techniques, and procedures has challenged leaders throughout the ages. Since the terrorist attack against the US on 11 September 2001 it has become imperative to understand that the face of warfare has changed. A thinking adversary, and they all are, will not face the US with fielded military forces on the open battlefield, but will seek asymmetric options to capitalize on US vulnerabilities.

For the most part the Global War on Terror is not against nation states, but against organized networks of non-state actors who operate freely and internationally. The US has a military that more than matches the military of any nation in the world—but is it equipped with the capabilities to effectively wage war against organizations that have a small footprint, are frequently on the move, and present opportunities as targets for moments at a time then fade into the global environment? Radical change is in order to meet the challenges presented by present day terrorists.

The right approach to continuing education for space professionals could very well be the key. Current instruction on space through AETC and the NSSI provides an outstanding baseline of knowledge throughout the space professional's career, but space professionals should cultivate an understanding of how to fight space systems through continued education. What do we, as space professionals, bring to the fight, and how do we inject space capabilities into the warfighting planning cycle? Like Airmen, "spacemen" should be capable of articulating warfighting effects through space capabilities in a real and meaningful manner. It is the view of this author that continuing education could take the form of guided discussions, and practice-by-doing techniques within the work center. It is entirely feasible to post quarterly scenarios on a common web site for space professionals to individually develop a course of action (COA) to resolve the scenario with space capabilities. Then the individuals in the work center could come together for COA comparison with each other and learn from each others perspectives and experiences. Finally, the COAs developed within the work center could be compared with the COA provided on the web site. Activating participative learning techniques through guided discussion and hands-on application would not only increase the retention of critical space capabilities, but also advance the development of space strategists. This method of continuing education is warfighter-focused, and benefits junior and senior space professionals wherever they may be. Scenario-based, table top "wargames" are simple and effective, and do not require millions of dollars of computer assistance, travel expenses or large teams of arbitrators.

Developing strategists through the use of table-top COA development dates back to the time of the pharaohs. Unlike the days of great Egyptian armies that ruled a large portion of the known world, US space professionals do not learn strategy sitting on the laps of their fathers. US military leaders no longer develop out of aristocratic families, but rise out of the population from all socio-economic levels. Strategic thought is not reserved for the elite, but developed in all military leaders.

Conclusion

"Life is the art of drawing sufficient conclusions from insufficient premises." - Samuel Butler, Notebooks

Red Flag did not develop out of convenience, but out of necessity, and in an austere economic environment. The leaders of that time did not wait until the funding cycle caught up with the need or until a more opportune time. General Dixon and his staff made the hard call to establish Red Flag because it was the right thing to do. This article challenges Air Force leadership to consider the value of scenario-based COA development, and its inclusion into all areas of space professional continuing education. The Air Force works, trains and fights as a team, but develops our military leadership as individuals.

Space professionals who have greater retention of the information taught during the space curriculum have a greater opportunity to be more effective than those who retain less information. COA development in the work center allows participants the ability to try new concepts in new situations. It also involves participants in the learning process. More than improving retention rates scenario-based COA development will dramatically improve space professional knowledge of applying space capabilities to real situations. Space professionals must be able to think critically, and develop as strategists to lead the next American warriors in the challenges of the future.

Notes:

[1] General (USAF, retired) Howard W. Welch, personal letter to Tom Clancy, author of *Every Man A Tiger,* 19 August 1999.

[2] Maj Gen (USAF, retired) George A. Edwards, Jr., personal letter to Tom Clancy, author of *Every Man A Tiger,* 7 October 1999.

[3] Guidebook for Air Force Instructors, Air Force Manual (AFMAN) 36-2236, 15 September 1994, 1.6, 4, http://www.hill.af.mil/me/DownloadableFiles/AFMAN36-2236.pdf (accessed on 18 October 2006).

[4] Ibid., 1.4, 1.

[5] Ibid., 13.1, 92.

[6] Dr. Richard, M. Felder, *Learning by Doing*, Chemical Engineering Education, 2003, 47(4), 282-283.

[7] Ibid.

[8] AFMAN 36-2236, 13.4.2.3, 93.

[9] Ibid., 1.4.1, 1.

[10] Ibid., 14.2.1, 100.

Maj Marc A. Peterson (BS, Advertising/Marketing, Oklahoma State University; MS, Human Resource Management, Lesley University, Massachusetts; MS, Air Command and Staff College, Maxwell AFB, Alabama) is the Chief, Bases and Units Branch, Basing and International Affairs Division, Plans and Programs Directorate, Air Force Space Command (AFSPC), Peterson Air Force Base, Colorado. He is responsible for leading command-level planning affecting installation and systems activation/inactivation, unit beddown, and base realignment actions involving AFSPC space, launch, and missile resources.

Book Review

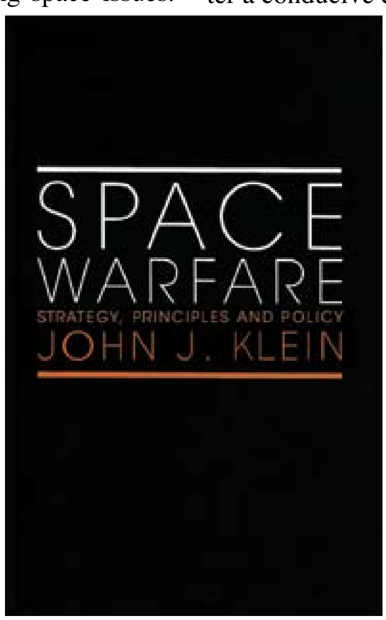
Space Warfare: Strategy, Principles, and Policy

By John J. Klein. New York, USA: Routledge. 2006. Appendices, Notes, Bibliography, Index. Pp 196. $119.99. ISBN: 0-415-77001-7.

Space strategy may be a relatively new field of study, but that does not mean it is wholly uncharted. Everett Dolman's *Astropolitik,* Colin S. Gray's *Modern Strategy,* David E. Lupton's *On Space Warfare,* Steven Lambakis' *On the Edge of Earth* among others are already familiar to the well-read space strategist. To this list of foundational works we must add Klein's *Space Warfare*. Klein, a US Navy Commander and naval aviator, has published a remarkable work in scope and breadth that, while possibly too self-restricted, is essential reading to all interested in space strategy.

In *Space Warfare,* Klein presents his case that space strategy is best served by applying a maritime model to space warfare, rather than the more common air or sea "power" model (expanding on his Naval War College Review essay "Corbett in Orbit"). Drawing especially from Sir Julian Corbett's *Some Principles of Maritime Strategy,* Klein modifies classic maritime concepts to add some powerful ideas to space power thought. The *celestial line of communication* (CLOC), the "lines of communication from, into, and through space used for the movement of trade, material, supplies, personnel, spacecraft, military effects, and electromagnetic transmissions" is a deceptively simple but profound idea that elegantly accounts for the unique dual nature of space as a pathway for signals as well as a physical medium. *Command of space* then becomes the ability to use CLOCs while denying the enemy use of the same, another seemingly obvious but inclusive clarification of the *summum bonum* of space strategy.

Clarity is the paramount gift of Klein's model to the strategist. Space thought is often filled with jargon with disputed meanings. Terminology of space concepts in Joint and US Air Force doctrine manuals are often incongruent, leading to as much debate over semantics as strategy when discussing space issues. Is an action offensive counterspace, defensive counterspace, or space control? By adapting well understood and historical strategic concepts to space, Klein performs a valuable service by separating the wheat from the chaff of space theory with efficient language, leaving the debates over terminology to the doctrinaires.



Klein, however, does not stop with simple definitions. Klein's belief that maritime strategy fits the space arena leads to specific strategic advice also derived from Corbett. Offensive and defensive operations, strategic positions, blocking, and the concept of using space as a barrier are all discussed to advantage. An intriguing assertion, that space forces should be physically dispersed but also retain the ability to "rapidly concentrate force and effects," seems a radical departure from the commonly accepted war principle of concentration and will occupy space theorists for a long time. This is as it should be, since Corbett's idea for sea forces was every bit then, and is still today, a very controversial topic.

Klein's maritime model is not perfect, and there is likely much debate ahead for many of his ideas. Klein attempts to prove that current space strategy is too preoccupied with the offensive, and one of his conclusions is that defensive space strategy (the "stronger" form of warfare according to Carl Von Clausewitz, he points out) should be more widely adopted and studied. Though defensive space strategy is important, Klein does not ignore the more "effective" form of offensive warfare, but doesn't fully articulate the maritime view of the offensive to the work's detriment.

Given the exceptional quality and insight of this book, Klein's recommendations and final thoughts are somewhat disappointing. After completely re-describing space strategy in a clear, consistent model and introducing many new strategic concepts and terms to the field, his conclusions are exceedingly conventional. In the majority of his conclusions, Klein presents nothing really new. Meekly advising that we uphold the current space legal regime, proceed with space weaponization only when absolutely necessary, wait for the inevitable independent space service and focus on the defensive space war seem to imply Klein is more interested in playing it safe rather than following his strategic thought to conclusion. Klein's suggestions are excessively flimsy and yield easily to arguments against this lukewarm advice previously stated by authors such as Dolman. A broad and bold reinterpretation of strategy defending the status quo is often unfulfilling, and Klein's concluding chapters do not escape this fate.

However, one of Klein's recommendations is extremely timely. Klein recommends that a Space War College model be immediately founded. Klein argues "an action like [establishing a Space War College] would indicate to the professional military community that space warfare is a subject that deserves separate and dedicated strategic study [and] … such a move would foster a conducive environment where more fully developed strategies for space warfare could be contemplated." Klein does not mention the National Security Space Institute (NSSI). It is unclear whether Klein does not consider this close enough to the Space War College to merit an acknowledgement or was not aware of it at the time of writing, though one suspects the latter. What is essential is that the leadership of the NSSI embrace Klein's vision. The NSSI should reach above its current mandate merely to teach and should instead strive to become the center for advanced space thought, where a new breed of strategists will discuss, debate, and forge the space strategies and theories that will ensure free nations will dominate space in service to all mankind. With Commander Klein's groundbreaking *Space Warfare* in hand, the strategists of the final frontier will be well armed for the journey.

1st Lt Brent D. Ziarnick, USAF, 50th Space Wing Tactics.

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