AIR FORCE SPACE COMMAND

Volume 3, Number 3

HIGH FRONTIER

THE JOURNAL FOR SPACE & MISSILE PROFESSIONALS

INSIDE:

Striking a Balance Between Risk and Innovation

Space Innovation and Development Center, "Unlocking the Potential"

Space Innovation is the Key to Providing Combat Power

SPACE INNOVATION

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High Frontier, Air Force Space Command's premier space professional journal, is published quarterly. The journal provides a scholarly forum for professionals to exchange knowledge and ideas on space-related issues throughout the space community. The journal focuses primarily on Air Force and Department of Defense space programs; however, the *High Frontier* staff welcomes submissions from within the space community. Comments, inquiries, and article submissions should be sent to AFSPC.PAI@peterson.af.mil. They can also be mailed to:

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Cover: Space Innovation
Sources: Air Force Space Command

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The Journal for Space & Missile Professionals

May 2007 Volume 3, Number 3

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Introduction

General Kevin P. Chilton
Commander, Air Force Space Command

"Imagination is more important than knowledge. Our knowledge is limited to all we now know and understand, while imagination embraces the entire world, and all there ever will be to know and understand." ~ Albert Einstein

For an entire year, we've been building towards this edition of the High Frontier. Very few concepts truly embrace the creative spirit and dedication of the men and women of Air Force Space Command like the theme of this journal—"space innovation." We are, by our very nature, innovators, in attitude and effort. Systems like the Global Positioning System, the Defense Support Program, and the Minuteman III are all testimony to the pioneer spirit of those before us and those who serve today. Innovation is the foundation of both our Service and Command and also serves to maintain the unmatched advantage from space our Nation enjoys today. Inside this edition, you will find opinions and insights from some of the most recognized innovators in the National Security Space enterprise on a variety of topics related to the ingenuity prevalent in today's space and air community.

We can think of no better organizations to begin this issue's discussion of innovation than the Air Force Research Laboratory (AFRL) and the National Reconnaissance Office (NRO). In our Senior Leaders Perspective, Maj Gen Ted Bowlds, AFRL's commander, masterfully frames the delicate issue of balancing the relative levels of risk and innovation necessary to preserve the capabilities we have today while reaching beyond our current designs to craft the United States' future space systems. He successfully defines not only the relationship between risk and innovation, but also between AFRL and our acquisition arm, the Space and Missile Systems Center. And, we are very privileged to have Dr. Pete Rustan, the NRO's director of Advanced Systems and Technology provide his perspective on those technologies that have shaped our space capabilities during the past 50 years and the management trends driven by those developments.

Other distinguished authors and experts in their fields also provide thoughtful views on innovation. The president and CEO of the Space Foundation, Mr. Elliot Pulham, dissects this notion into a comprehensive model, composed of five distinct facets, each laced with promise, as they relate to our trade. Col Larry Chodzko reviews the vision of the Space Innovation and Development Center and introduces readers to the dedicated team that is rapidly providing superior capabilities to the Joint Fight.

Everything we do in our Command is dedicated to the Joint Fight and we count on the resourcefulness and ingenuity of the Air Force men and women to advance the next generation of space systems. It is through the spirit resident in the people we work alongside every day that we maintain our asymmetric advantage in space, an advantage upon which the warfighter depends. The team at AFRL's Space Vehicles Directorate, the technology arm of the Air Force, has crafted a solid investment strategy in response to objectives laid out in national policy, and is working hard to deliver concrete results in a highly fluid environment. Similarly, the National Aeronautics and Space Administration (NASA) seeks to meet national objectives as a facilitator and catalyst for creativity in their Innovative Partnerships Program. This dynamic process presents mutually beneficial opportunities for scientific and industrial growth to both NASA and a multitude of government, industry and academic organizations in an effort to promote and progress new technologies.

From the "Industry Perspective," we're fortunate to capture views from Mr. Elon Musk, CEO and CTO of Space Exploration Technologies (SpaceX) and Dr. Alexis Livanos, corporate vice president and president of Northrop Grumman Space Technology. Mr. Musk's unique perspective, both as entrepreneur and passionate advocate for our Nation's space industry, provides an unvarnished look at possible future challenges to our Nation's unmatched space advantage. Dr. Livanos, an equally strong advocate for the National Security Space enterprise, chronicles advancements in our space systems from an acquisition perspective, citing the complicated process we often face in our procurement sector.

In this installment's "Warfighter Focus," Lt Col George Farfour presents a thought-provoking essay on the role of Airmen in the innovation process as well as the commitment each of us must make, as the experts and leaders in space, to expand the capabilities we provide to the Joint Fight. Maj Carolyn Wood's focus on developing a standardized documentation tool to streamline the credentialing process for space and missile operators maps a path to success for this complex and daunting task at the operational wings, demonstrating the creativity resident within our ranks today.

Every article in this journal is intended to spur further thought and encourage debate on issues this community grapples with every day. It is essential we understand the complex nature of our business and understand opposing viewpoints on contentious issues. We hope you enjoy all this edition has to offer and look forward to hearing more views from the innovators in the field.

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.

Striking a Balance Between Risk and Innovation

Maj Gen Ted F. Bowlds
Commander, Air Force Research Laboratory
Wright-Patterson AFB, Ohio

There are several ways to define the relationship between risk and innovation. Probably the most common approach is to balance the risk of applying innovation to help solve a need against maintaining the current status quo. Another is to look at the risks that exist to fostering innovation. The following is a discussion of what we at the Air Force Research Laboratory (AFRL) are doing to address both of these challenges and some examples of our success; but first we need to establish a framework of understanding.

Innovation is an action. Webster's Dictionary defines innovation as the act or process of introducing new methods, devices, and so forth; a change in the way of doing things. For example, from a practical military perspective innovation can result from introducing a new weapon system or using existing systems in new ways. We do this to provide a new capability or enhance an existing capability by making it more effective or more affordable. Risk, on the other hand, is a measure. Used in the context of innovation, risk can measure your ability to create innovation or the potential consequences of applying innovation.

Creative people and a motivating work environment are the two primary ingredients necessary to ensure the genesis of innovation. The organization must develop these ingredients. First, training and higher education enhance the creativity of the workforce. Next, creative people require a flexible environment that rewards thinking "outside-the-box." Finally, stable funding for research is an important element to foster creativity.

The most innovative idea in the world has little value if there is no application. Therefore the successful application of innovation requires close interaction with customers (in our case, the warfighter) to identify their needs; however, the interaction doesn't stop there. As the idea matures the customer needs to stay engaged to help in refining the innovation and enable the implementation plan development (i.e., concept of operations [CONOPS]). This transition into operations must be planned carefully to avoid the all too common mistake of placing advanced technologies on a weapon system's critical path before they are sufficiently mature. Conversely, if system development plans are too averse to incorporating innovation enabled by advanced technologies they will be locked into providing reduced capabilities. With the rapid global advancement in military capabilities and the rapid escalation of the cost of military operations, suboptimizing our military capabilities is not an option.

AFRL is working towards assuring we have the ability to both create innovation and facilitate the smooth transition into operational systems. As with most organizations, people are our greatest resource. The AFRL workforce comprises about 9,500 people in the laboratory's component technology directorates and the Air Force Office of Scientific Research. Within the government workforce about 3,000 are scientists or engineers. Of these over half have advanced degrees with more than 700 having PhDs. All these people work at 10 major research sites across the country in facilities having a $1.8 billion replacement value and $1.7 billion worth of equipment. The total appropriated annual budget for AFRL is approximately $2 billion, of which over $200 million is executed by the Air Force Office of Scientific Research. Much of this funding is awarded to universities for cutting edge research in the basic sciences. AFRL also receives approximately $1.7 billion per year from outside sources to conduct research supporting the Air Force mission. This affords our researchers to both work on cutting edge technologies in-house and keep abreast of advances throughout their areas of expertise, providing a fertile environment for creating innovation.

Within the space community, we have several processes to foster interaction between AFRL and our primary customer, Air Force Space Command (AFSPC). Many of our current processes can be traced back to actions taken after the publication of the Commission to Assess United States National Security Space Management and Organization report published in 2001. For example, we work closely with the Space and Missile Systems Center (AFSPC/SMC) within the construct of our Program Executive Officer/Technology Executive Officer Review process. The primary objective of this umbrella process is to identify AFSPC/SMC's technology needs in its currently established systems, developmental programs, and future programs. In turn, AFSPC/SMC reviews and validates whether AFRL's technology portfolio is progressing towards viable solutions to its needs and identify mutually supportable transition points for these technologies. While this process works well for more near and mid-term needs, we must also pursue other interactions with AFSPC to ensure far-term needs are not overlooked. Semi-annual Space Technology Councils are held with AFSPC leadership to review the overall space science and technology (S&T) program and provide guidance. Formal AFSPC guidance is published as part of the Strategic Master Plan that provides insight into AFSPC's needs beyond 20-plus years, as well as their technology priorities in the near, mid, and far-term. While these processes worked well to identify customer needs and develop candidate innovative solutions, they didn't always produce viable transition plans that balanced the risk of introducing these innovations with the customers' desire for greater system capability. Something else was needed.

Recently the Executive Agent for Space introduced his "Back-to-Basics" acquisition approach to provide a structured way to introduce innovation into space acquisitions without overt risk to program success. This approach views acquisitions as a continuous process with four distinct but interrelated stages. The first stage is S&T, where we conduct basic research and explore the possibilities of new technologies. In the second, technology development, we evaluate the utility of discoveries made in the S&T stage with our customers. The third stage is systems development, where AFSPC/SMC takes the most promising technologies and matures them to higher readiness levels so they can be integrated into operational platforms in the fourth stage, System Production. This approach manages, or apportions, risk by accepting higher risk in those beginning stages; it lowers the risk in System Production by incorporating only proven technologies and taking smaller, more manageable steps. By doing so, we allow a constant, on-going rhythm of design, build, launch, and operate that should reduce the cycle time for space product acquisition, insert stability into our production lines and workforce, and enable us to field better systems over time. This approach will deliver timely, affordable capability to the warfighter while increasing confidence in our production schedule and cost.

To illustrate the application of some of the principles discussed above, here are some examples of space innovations we are working on at AFRL:

Space Situational Awareness (SSA)—AFRL has initiated our Rapid Reaction Process in response to a warfighter's urgent need in the Joint Space Operations Center. The AFSPC/SMC Commander and the Commander, Joint Functional Component Command—Space identified the current challenges to plan, direct and execute space superiority at the operational level of war. Underpinning these challenges is the need for SSA that is persistent, provides real-time status, dynamically changes detection and identifies intent. They stressed we ought to link together and utilize our current sensors more effectively before adding more sensors, underscoring the use of existing tools, capability, phenomenology, and so forth to make the most of our existing data to provide a more comprehensive picture of the status of objects in space. AFRL assembled a team of technologists, users, and acquisition experts to tackle this problem by applying emerging, near term technology to deliver a functional, field-testable prototype. There are a total of four spirals planned to gradually add functions and upgrades, in a process of continuous improvement.

XSS-11—The very successful XSS-11 micro-satellite demonstrated a new class of low-cost satellites weighing approximately 100 kilograms dry mass, exploring a variety of key system technologies important to future military applications such as space servicing, diagnostics, maintenance, space support, and efficient space operations. Micro-satellites, such as XSS-11, offer affordable platforms to demonstrate key capabilities like autonomous mission planning, rendezvous and proximity operations and other enabling technologies. While this program was not originally directed at any specific AFSPC mission area, AFRL employed XSS-11 to demonstrate synergistic technologies and operations necessary for the development of space systems needed to meet a wide variety of possible AFSPC's future needs. These technologies and operational concepts, as well as the lessons learned, are being documented and transferred to the operational community to facilitate development of future space concepts and systems. In addition, the 14th Air Force participated with the XSS-11 flight team during the second sortie as part of an experiment with possible command and control concepts for the application of these types of future systems.

TacSats—The TacSat program originated as a multi-agency, multi-service set of experimentation activities aimed at fulfilling the Air Force Chief of Staff's concept for Joint Warfighting Space (JWS), AFSPC/CC's Joint Warfighting Space Directive, and AFSPC/XO's Draft JWS CONOPS. The program strategy contained four parts: the Service laboratories and other national entities (such as Jet Propulsion Laboratory, Applied Physics Laboratory, etc.) invest in required S&T, conduct robust space experiments, conduct military utility assessments and CONOPS experiments, and plan for acquisition of operational capabilities. It has since become the centerpiece of the congressionally mandated operationally responsive space program development which, if successful, could herald a new paradigm for space system development, acquisition, deployment, and operation. The first of several TacSat experimental spacecraft (TacSat-2) is currently on-orbit and undergoing initial testing in preparation for operational experimentation by the user community.

In closing, balancing risk and innovation is not an exact science but an art. It takes continuous attention and evolving processes to ensure we are able to maintain our technological leadership and translate that into superior warfighting capabilities without costly failures or delays. We have a rich history of both great success and missed opportunities. With the ever increasing speed at which global military advantage can shift, we must continue to aggressively, but prudently, pursue innovation to ensure our national security.

Maj Gen Ted F. Bowlds (BS, Electrical Engineering, Mississippi State; MS, Electrical Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio) is commander, Air Force Research Laboratory, Wright-Patterson AFB, Ohio. He is responsible for managing the Air Force's $2 billion science and technology program as well as additional customer funded research and development of $1.7 billion. He is also responsible for a workforce of approximately 9,500 people in the laboratory's component technology directorates and the Air Force Office of Scientific Research.

General Bowlds entered the Air Force in 1975 through the ROTC program. In earlier assignments, he served as an engineer in an Air Force laboratory and as a flight test engineer on the F-117. He has worked as avionics program manager on the B-2, bomber branch chief at the Pentagon, chief of Advance Medium Range Air-to-Air Missile development in the AMRAAM System Program Office, and as commander of the Rome Laboratory in Rome, New York.

General Bowlds also served as the deputy director of Global Power Programs with the Office of the Assistant Secretary of the Air Force for Acquisition, Headquarters US Air Force, Washington, DC. Prior to assuming his current position, he was assigned to Wright-Patterson's Aeronautical Systems Center as deputy for Acquisition.

Senior Leader Perspective

Developing and Maintaining the Innovative Edge

Dr. Pete Rustan
Director, Advanced Systems and Technology
National Reconnaissance Office

Sputnik 1 was launched 4 October 1957, marking the beginning of a new era. As the space industry's 50th anniversary approaches, it is imperative to reflect on the growth of the use of space for many applications. From that first application, communicating simple data one-way space to ground, space missions today have significantly increased (see table 1). Since these missions have become vital not only to the Department of Defense but also to the US industrial base, it is essential to continue to develop and maintain the innovative edge.

- *Global communication*
- *Space science and exploration*
- *Space transportation*
- *Environmental sensing*
- *Position, navigation, and timing*
- *Missile warning and surveillance*
- *Intelligence, surveillance, and reconnaissance*
- *Space control*

Table 1. Space Missions.

This article represents the author's view about some of the groundbreaking space technology programs that enabled these missions and some of the program management processes used to acquire these satellites. Since problems have been found in the acquisition of our space systems, the article addresses some of these problems and makes some specific recommendations. Finally, the article includes a detailed description of some of the innovative technologies and processes that must be integrated in the space industry to take full advantage of the recent advances in information technology (IT) and information systems (IS). These advances will enable more efficient and rapid transfer of collected information by using the global Web network dissemination and easier access.

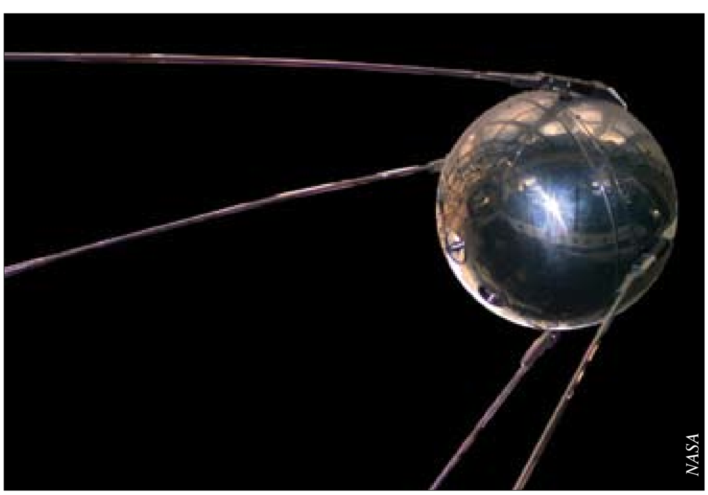

Figure 1. Sputnik 1.

Trends in Science and Technology Initiatives

Science and technology developments in the various bus subsystems (power, structures, attitude control, propulsion, command and data handling, thermal, and communication) and payloads (e.g., telescopes, radio-frequency [RF] electronics, laser communication) have enabled a significant increase in space systems capabilities. I will analyze six satellite technologies or subsystems, over the last 10 to 25 years, examine the relative trends of those technologies, and speculate about possible future trends. Lastly, I will examine the potential trends in nanotechnology and miniaturized components.

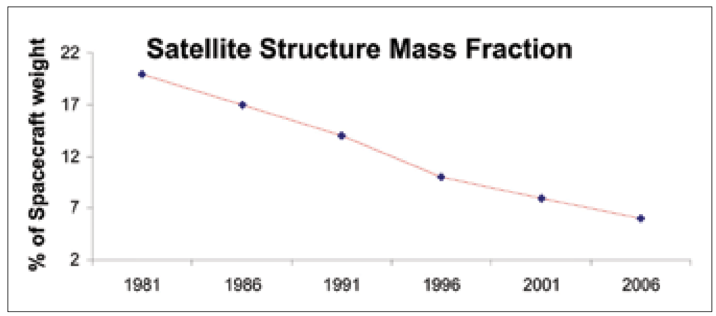

Figure 2. Percentage of satellite structure mass fraction (structure weight ÷ satellite dry weight).

Figure 2 shows the significant decrease in the average weight of satellite structure as compared to the total satellite dry weight. In the early days, satellite structures were primarily built of aluminum. As various composite materials such as honeycombs, metal matrix and metal resin composites, carbon, and graphite were introduced the average weight of the structure was reduced from about 20 percent in the early 1980s to about six percent today for some specific applications. This reduction in the satellite structure has produced an increase in the payload mass ratio; thus, providing a higher percentage of the satellite weight for payload functions. The potential introduction of carbon fibers and carbon nanotubes to build the satellite structures should continue to decrease the weight of the satellite structures.

Figure 3 on the following page shows the average power density for the electrical power system from 1981 to 2006. These evolutionary advances are a product of continuous increases in the efficiency of multiple junction solar cells, the increased storage energy density of nickel hydrogen batteries and the efficiency of the power conversion and distribution systems. During the last 25 years, there has been an order-of-magnitude improvement on average power density (watt per kilogram). The introduction of additional junctions in multi-junction solar cells, the use of solar cells using nanotechnology, and the significant increase in the energy density of lithium-ion batteries should double the efficiency of the electrical power system dur-

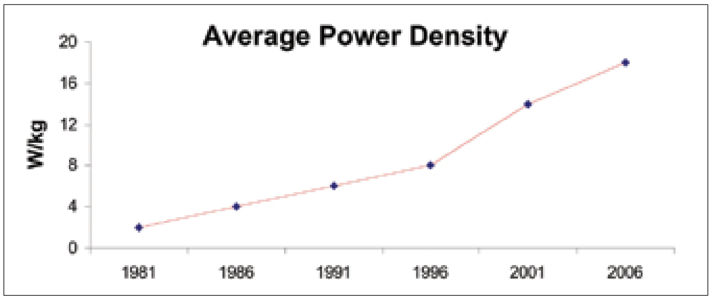

Figure 3. Average power density in watts per kilogram for spacecraft electrical power system.

ing the next 10 years. This increase will be needed to support the new generation of power hungry payloads without having to increase the size of the solar panels.

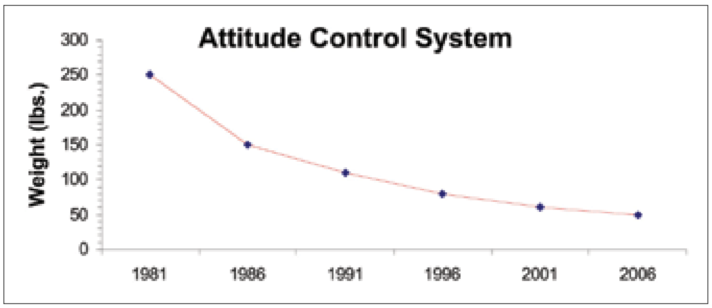

Figure 4. Relative weight of a spacecraft attitude control system for a fixed capability.

Figure 4 illustrates the relative reduction of the weight of a satellite attitude control system for a fixed set of characteristics such as position, knowledge, and control. Significant reductions on the weight of star cameras and the introduction of global positioning system (GPS) receivers coupled with significant reductions in the weight of various actuators (reaction wheels, control moment gyros, magnetometers, inertial reference units, thrusters, and various others) used for satellite control systems have produced a weight reduction of a factor of five during the last 25 years. Additional weight reductions are expected by using the latest generation of microchip technologies in star sensors and GPS receivers, and by using lighter weight materials for the various reaction control actuators.

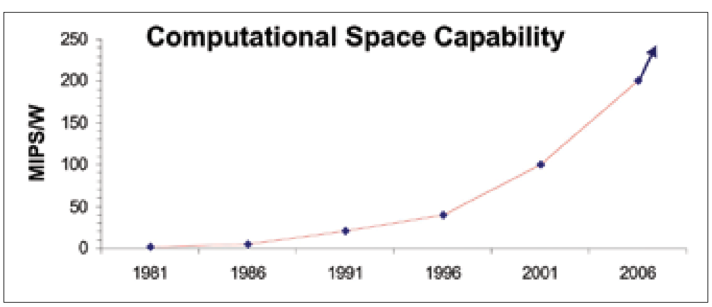

Figure 5. Millions of instructions per second capability per unit watt.

Figure 5 illustrates the truly revolutionary developments over the last 25 years in the command and data handling functions. Since this subsystem is directly impacted by the latest commercial technologies, and computing technologies have been advancing in accordance with Moore's Law (increasing speed by a factor of two every 18 months); the number of millions of instructions per second (MIPS) per unit power has increased by more than two orders of magnitude. Additionally, advances in compact storage and onboard processing functions have continued to provide a significant capability. However, since space computers must be operated in the space radiation environment, radiation hardening is required. At this time, the space industry is about eight years behind the terrestrial commercial computer market. It takes about eight years to produce a radiation hardened version of the latest commercial computers. There are several research efforts to reduce this cycle by learning to build radiation hardening by design or by using advanced materials.

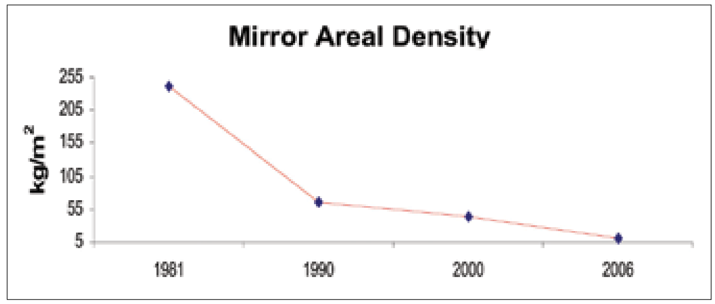

Figure 6. Average mirror areal density for various mirror materials.

Figure 6 shows the trend in mirror areal density over the last 25 years, from the initial 240 kg/m^2 used in the Hubble Space Telescope in the early 1980s to about 10 kg/m^2 in 2006 for some specific materials. Depending on specific applications, several mirror materials have been used for space telescopes. The most common mirror materials are glass (used by the Hubble Space Telescope), zerodur (used by the Quickbird satellites), beryllium (used in the James Webb Space Telescope) and silicon carbide (used in the 3.5 m ESA Herschel Space Observatory). This significant decrease in the mirror areal density when coupled with weight reduction in other telescope and detector technologies is producing a significant reduction in the total weight of space telescopes.

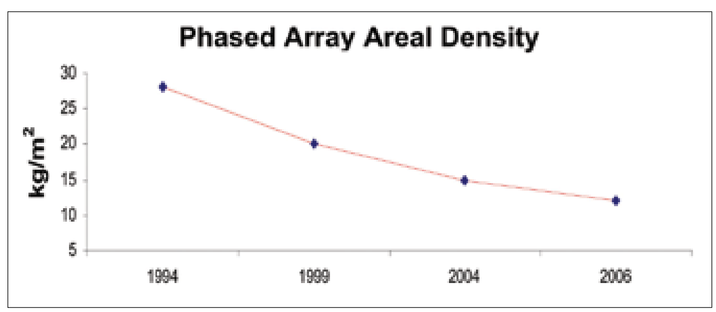

Figure 7. Average active phased array areal density.

Finally, Figure 7 shows reduction in the weight of active phased-array technologies from about 28 kg/m^2 in the early 1990s to about 12 kg/m^2 today. This weight includes the active and passive elements mounted on the antenna but it does not include the weight of the RF electronics. These advances will enable the efficient use of phased-array antennas for synthetic aperture radar missions.

These specific reductions in satellite weight coupled with similar progress in other satellite subsystems and components have reduced satellite weight by a factor of about two every eight years since 1981. This shrinking satellite trend is not evident because the benefit of the weight savings is used to significantly increase capabilities.

Nanotechnology and Miniature Components

In addition to the continuing advances in traditional technology areas over the last 25 years, significant improvements can be made by integrating nanotechnologies, micro-sensors, and miniature components. They are essential to enable our new generation satellites, allowing for vastly increased capabilities and smaller and lighter satellites. Government and industry should also investigate the impact of nanotechnologies on launch vehicles. Nanotechnology will realize the dream of single stage to orbit for medium sized satellites.

There is no single technological advance that is likely to have such a dramatic long-term impact on our space systems than nanotechnology. New advances in nanoscale science and technology are occurring at a very rapid rate.[1] Nanotechnology will provide powerful (in the petaflops range), compact, low-power, radiation hardened onboard computers, allowing for autonomous intelligent vehicles. There are three areas of nanotechnology: materials, electronics/computing, and sensors/components.

Materials are nanotubes, nanolaminates, and multifunction structures. Nanotubes, using thin cylinders of carbon graphite, are an ideal material for the construction of large space structures. They are expected to have 100 times the tensile strength of steel, thermal conductivity at least as good as diamond, and a theoretical electrical conductivity 10,000 times better than copper. Large scale production of high quality nanotubes is in its early stages, but far more advanced than graphite fiber production was during its first few years of development.

In the nanolaminates area, the most relevant work is in the fabrication of composite layered materials, where each layer is a few nanometers (nm) thick and fabricated one layer at a time. Some of the important properties of nanolaminates include significant added strength and a reduction in thermal conductivity. Ion milling could be used to "finish" a nanolaminate surface to diffraction limited surface figure. Nanolaminates could be used to strengthen mirrors to achieve very low areal densities.

Another key aspect of nanotechnology materials is the ability to engineer multifunctional properties. For example, a top layer could be a tough protective layer with adaptive emissive properties, another layer could contain tactile response sensors and chemical detectors, while a third layer could be a high strength structural layer for energy storage. The similarity to biological systems, eventually to include self-repairing functionality, will allow very advanced spacecraft to be protected against the impact of small particles.

The second major focus of nanotechnology is in the area of electronics and computing. Nanoscale electronics will likely be as revolutionary to conventional microelectronics as conventional microelectronics was to integrated circuits. It will enable us to press Moore's Law to the atomic level and create compact, low-power, low-cost computers with 100 times the clock rate, 100 times the MIPS and 1,000 times the floating point operations per second.[2] It is well within the limits of novel nanoscale systems to produce transistors and memory cells only 10 nm across, with circuit element characteristics very different from today's concepts. They include using silicon nanowires as the gate between the source and drain and molecules acting as complete electronic components (e.g., transistors, memory cells). Industry is exploiting these properties to demonstrate memory with a density of 100 billion bits/cm^2 and circuit components 10,000 times smaller and about 100 times denser than today's micro-computer.

Lastly, nanotechnology can be used to build miniature sensors and components. An important feature of nano-scale systems is that they can exhibit properties not seen at a larger scale. Change or affect one atom and the behavior of the entire system can be noticeably altered. This feature can enable systems that are responsive to a single molecule, atom, electron, or photon. For example, very small quantum dots can be used to make devices responsive to a single electron. Currently, carbon nanotubes and silicon nanowires are being developed as very low voltage electron emitters, due to their very sharp tip, very large gradients can be created at a very low voltage. The key challenge from a space systems point of view will be to integrate sensors and components into multi-device modules and further integrate modules into larger scale systems. Some challenges include interconnected electrodes, signal readout and processing, thermal control and contamination.

I have described why advanced technology, both evolutionary and revolutionary, is vital to the space community. But all this is for naught, unless government and industry personnel can properly manage these technology initiatives. Spacecraft management processes must be modified and improved to quickly bring new and improved capabilities to the military and intelligence communities.

Space Program Management Processes

In the early days of the space program, creativity drove the advances around the world of the fledgling space industry. Scientists, engineers, and managers were highly motivated and focused on specific objectives. There was no pre-established expertise about the various technologies or missions, people were free to use their creative thinking skills and continue to try new things. Indeed, manuals were revised daily to add any additional tests that had been proven useful. Single mission satellites were built in about a year and quickly lifted to orbit. Many of these satellites or the rockets that launched them did not work. There was tremendous passion and courage based on the needs of the Cold War. President John F. Kennedy added specific emphasis in 1961 when he declared, "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth."[3] During these early days, some program management techniques were being developed strictly on what worked to reduce cost and schedule and/or to increase performance. From the earliest programs, all parties realized space applications would not be limited to the scientific and commercial realms, but quickly expanded to include military and defense related applications.

By the early 1990s, the space industry had matured significantly. Rigorous procedures were developed to treat space with the same requirement-driven processes used in the aircraft industry. There were no specific rules to guide which type of payload functions should be integrated into any specific bus to meet customer requirements. By attempting to minimize launch vehicle costs, which had become quite expensive, satellites were built to meet the maximum lift weight of the rocket for each specific orbit. The combination of these factors (requirements, multiple payloads per satellite, few launch vehicles) drove the space industry to introduce certain practices, which today may not be conducive to obtaining a best value proposition. In my opinion, there are ten major government/industry space acquisition problems. The following are proposed potential innovative solutions to address these problems (see table 2):

1) *Overly detailed process to translate users' requirements into fielded systems*
   Requirements-driven systems engineering processes presently used to translate the voice of the user are only effective for incremental improvements of large programs with modest gains. Major advances are never made by analyzing requirements. Instead, breakthrough technologies produce the truly innovative capabilities. Government program managers (PM), users and industry leaders should have disciplined, iterative discussions about the desired solutions and investigate new enabling technologies as much as evolutionary developments. This dialogue must include iterations to illustrate the relationship between increased and decreased capabilities and the corresponding impact to schedule, cost, and risk. The space management office should understand the guidance provided from this dialogue and, being keenly aware of enabling technologies, develop new programs. If problems develop, PMs should work with the users to balance performance and cost.
2) *Proceeding to acquisition before achieving technology maturity*
   Enthusiastic PM often want to start space programs before some of the critical technologies required for the mission have matured. Proceeding to acquisition before technology maturity often results on spending months or years maturing the technologies inside the program while paying for the standing army of non-recurring engineering while achieving little progress end-to-end. When building complex spacecraft that use newly developed technologies, it is essential to reach a certain technology and manufacturing readiness level before proceeding with acquisition.
3) *Inflexible budgets*
   Complex acquisition programs cannot be managed properly without having budget flexibility to solve problems as they develop. Space management organizations are much more successful if they can shift money around to meet existing needs while maintaining some reserve funds in the various programs to address potential problems.
4) *Requirements creep*
   Today's space assets are used by a large number of stakeholders and since the revolutionary advances in IT and IS are bringing great ground capabilities, it is easy to understand the user's desires for the latest capabilities. The incorporation of new capabilities after final design translates to schedule and cost increases. PMs, supported by senior management, must resist these efforts.
5) *Management experience shortfalls*
   As industry continues to build more complex spacecraft, attempts have been made to compensate for our present paucity of management experience in the government by significantly increasing the workforce on various programs. Contractors have responded by increasing their workforce to address issues raised by the government workforce. The effect is increased cost with less productivity. To end this spiral, government should hire more qualified individuals, minimize personnel rotations, and reduce the size of the government program offices and support contractors. Government and industry should also empower a smaller, focused employee team to make more independent decisions on their programs while holding them accountable for their actions. Retaining and effectively employing exceptional people are the keys to excellence in innovative science and technology programs.
6) *Poor subcontractor management*
   It is taking the prime contractor many months or years to finalize the specifications and the work of the subcontractors. Prime contractors often fail to perform a detailed system engineering analysis during the first few months of a program and do not communicate the specifications to the subcontractors. The government should require subcontracts to be finalized within the first few months of any satellite contract. Unless the PM can see the performance, cost, and schedule of all the subcontractors fully integrated in the Integrated Master Plan and Integrated Master Schedule, the government cannot have any confidence in the proposed execution presented by a prime contractor. The poor subcontract management and late requirements flow down also reflects the lack of good system engineering on the part of the space industry for which there is a paucity of

- *Overly detailed process to translate users' requirements into fielded systems*
- *Proceeding to acquisition before achieving technology maturity*
- *Inflexible budgets*
- *Requirements creep*
- *Management experience shortfalls*
- *Poor subcontractor management*
- *Uncertainty about electronic components*
- *New spacecraft for each set of requirements*
- *Forgetting about ground services*
- *Strict adherence to cost processes which reflect previous problems*

Table 2. Government/Industry Acquisition Problems.

such personnel who understand the systems and subsystems and the interplay between them.

7) *Uncertainty about electronic components*
With the tremendous advances in the microchip industry during the last 20 years, a large number of previously discrete components are being integrated into much more complex single parts. Since the market for these new components is driven by terrestrial requirements, these components might not meet the environmental conditions required to work in the space environment. Redesigning and extensive testing are often necessary to meet the radiation hardening, random vibration, acoustic or thermal vacuum requirements. Problems with the use of more than 20 years old space qualified electronic components are just as common as problems related to the use of brand new commercial components. This problem should be ameliorated with a vibrant space manufacturing industrial base that includes a large number of suppliers.

8) *New spacecraft for each set of requirements*
In spite of the continuing demand for satellites to meet the needs of various mission areas, manufacturers have a propensity to build a unique satellite for each specific application. To solve this problem, users should encourage the development of standard interfaces and modular plug-and-play configurations. The most effective approach to minimizing the nonrecurring cost associated with new satellite developments is to emphasize distributed satellite constellations and production assembly lines.

9) *Forgetting about ground services*
Too often, there is a tendency to isolate acquisition from the organizations responsible for analyzing and disseminating the products being obtained with the satellites. End-to-end analysis is required during the initial stages of the satellite design for all the systems used to convert data into products, information, and knowledge. Lack of this system engineering analysis often results in late, costly modifications to the satellite design. The ground infrastructure required to control the satellite and process and distribute the resulting information must be fully analyzed during the initial phase of the acquisition process to avoid optimizing the spacecraft at the expense of the ground system.

10) *Strict adherence to cost processes which reflect previous problems*
When the government builds a new satellite today, an independent cost estimate (ICE) is performed. Although the intention of this evaluation is to make sure the total program cost is understood and worthwhile to pursue, the ICE only reflects the cost of recent satellites using existing procedures. Since there have been acquisition problems during the last 10 years, the data used for the ICE assumes these problems will continue to occur by using the same procedures. To innovate today, it is necessary to break away from existing procedures and use the streamlined program management practices discussed in this paper.

Looking into the future, I believe there is also an inherent problem with the way the space industry builds satellites today. Rather than a traditional, stove-pipe development approach, the use of Web based systems for network based solutions where many engineers can work on the same problem and share their solutions instantaneously should be encouraged. Prototype development cycles can be reduced from months to a few days by using Computer Aided Design tools where circuit boards are designed and iterated to achieve the optimum solution in a matter of days. After initial prototyping, the Web can be used to solicit and produce large production runs. Small companies are emerging all over the world to perform product development without knowing specific applications. These small companies can save large companies a lot of time and significantly reduce time to market. Presently, our space industry does not capitalize on the advantages of rapid prototyping to build our satellites. On the contrary, our cycle time is increasing while the rest of the commercial sector is experiencing a true implosion in manufacturing and prototyping cycle times. Aerospace companies must be encouraged to develop interoperable standard interfaces with the more pure-private commercial companies. Unless satellite companies incorporate rapid prototyping, the space industry will not be revolutionized.

Other Leading 21st Century Technologies and Processes

In addition to the evolutionary and revolutionary technology developments and improved management processes, two IT/IS developments needed in order to maintain our innovative edge must be discussed. Space systems are an integral part of the network centric architecture, but by themselves, satellites are just a sensor or a communications link, it is only when they are fully integrated into the greater network that they become truly powerful tools.

Network Centric Architecture

The IT/IS advances in the Web today should be integrated to make the satellite a node in the global information network. Web 2.0 was the early evolution of the Internet from isolated entities (e.g., a means to send e-mail from one user to another) to a networked, social system (e.g., podcasts, Weblogs). The recent Web 3.0 allows transitioning from human orientated data manipulation to machine-processable information. Web 3.0 integrates a large number of sensors and appliances into the

Space systems are an integral part of the network centric architecture, but by themselves, satellites are just a sensor or a communications link, it is only when they are fully integrated into the greater network that they become truly powerful tools.

Internet platform to autonomously aggregate significant more information and to derive knowledge. With Web 3.0 global situational awareness can be achieved by integrating mass produced sensors with commercial products which are routed with Internet space platforms. For example, GPS enabled video cameras with cell phone capabilities can automatically be integrated with space and aircraft sensors into a Web 3.0 network centric, service orientated architecture. With the advent of an enormous number of devices, governments and companies will be migrating to Internet Protocol version 6 (IPv6). Currently, IPv4 supports 2^{32} addresses (about 4.3 billion), while IPv6 will support 2^{128} addresses, about 5×10^{28} for each of the 6.5 billion people alive today. In the IPv6 architecture, applications such as Wikis, YouTube, and iTunes can be an integral part of the knowledge that is enhanced by the autonomous integration of information collected from space.[4] Every developer in the network can create, modify, and post content while every user can access and manipulate that content. The users should have on-demand video instead of single pictures and text. The availability of a Web 3.0 network centric architecture with video and audio directly to the user will significantly improve productivity.

Conclusion

In the first 50 years of the space industry, a tremendous growth in space capabilities has occurred, from an initial simple communication mission to many complex missions. During this time, evolutionary and revolutionary technologies and processes have been developed and successfully implemented. This article presented the author's view of the most relevant technologies and processes. The technology advances illustrated here have reduced the structure weight by at least a factor of three, the average power density by an order of magnitude, the attitude control system by a factor of five, the computational space capability by at least two orders of magnitude, and the mirror areal density by a factor of 20 over the last 25 years. Newer technologies such as phased-arrays have benefited by better than a factor of two reduction in areal density in the last 12 years. These technologies and many others have continued to reduce the weight of a satellite by a factor of two about every eight years over the last 25 years for the same performance parameters. This satellite weight reduction is not easily noted because satellite capabilities continue to increase. Since serious problems with program management acquisition practices have been observed during the last 10 years, the author's perception of the most critical problems and proposed solutions are included. To develop and maintain the edge, one must be proactive and understand the opportunities and challenges in front of us as the space industry moves into the next 50 years. Therefore, a detailed analysis of nanotechnologies, rapid prototype, and network centric architecture is included because these technologies and processes will be essential to achieve the maximum performance and utility of space assets.

Notes:

[1] One nanometer is one billionth, or 10^{-9} of a meter. For comparison, typical carbon-carbon bond lengths, or the spacing between these atoms in a molecule, are in the range .12-.15 nm, and a DNA double-helix has a diameter around 2 nm. On the other hand, the smallest cellular lifeforms, the bacteria of the genus Mycoplasma, are around 200 nm in length, www.wikipedia.org.

[2] Moore's Law is the empirical observation made in 1965 that the number of transistors on an integrated circuit for minimum component cost doubles every 24 months. It is attributed to Gordon E. Moore, a co-founder of Intel, www.wikipedia.org.

[3] President John F. Kennedy, "Man on the moon," speech, special message to the congress on urgent national needs, 25 May 1961.

[4] A wiki is a Web site that allows the visitors themselves to easily add, remove, and otherwise edit and change available content, typically without the need for registration. This ease of interaction and operation makes a wiki an effective tool for mass collaborative authoring, www.wikipedia.org; YouTube is a popular free video sharing Web site which lets users upload, view, and share video clips. Videos can be rated, the average rating and the number of times a video has been watched are both published, www.wikipedia.org; iTunes is a digital media player application introduced by Apple for playing and organizing digital music and video files. Additionally, iTunes can download digital music, music videos, television shows, iPod games, various podcasts, and feature length films, www.wikipedia.org.

Dr. Pete Rustan (BSEE and MSEE, Illinois Institute of Technology, Chicago; PhD, Electrical Engineering, University of Florida) is currently the director, Advanced Systems and Technology Directorate, National Reconnaissance Office (NRO).

Dr. Rustan served a 26 year career in the United States Air Force, where he distinguished himself in the management of seven spacecraft development programs that used advanced technologies and implemented the "faster, cheaper, and better" approach to acquiring space systems. He was the mission manager for the Clementine spacecraft, which mapped the surface of the Moon and obtained more than 1.8 million images using 11 spectral bands. The construction and testing of the Clementine mission took just 22 months from concept to launch and cost only $80 million. The Clementine mission demonstrated for the first time that a fairly sophisticated spacecraft with six cameras could be built on a shortened schedule. Of scientific note, Clementine's radar returns strongly suggested the presence of ice on the Moon's South Pole.

During his last tour of duty in the military, which was coincidentally at the NRO, Dr. Rustan promoted and demonstrated that NRO mission objectives could be met by building a constellation of smaller and cheaper systems. Dr. Rustan remains an advocate for rapid prototyping and selecting the best value proposition that addresses our intelligence needs.

Dr. Rustan has received many national and international awards, including the Aviation Week and Space Technology Laureate and Hall of Fame, the Disney Discovery Award for Technological Innovation, the National Space Club Astronautics Engineer Award, the NASA Outstanding Leadership Medal, and was featured by Space News in their Top 100 in Space 1989–2004.

The Five Facets of Innovation

Mr. Elliot G. Pulham
President and CEO, Space Foundation

Innovation! What a powerful word. Veiled in the faint hint of patriotic, American "can do," the word fairly bursts forth from the chest. In our minds, it is essential to the space industry—at the heart of what we do and who we are, how we see and define ourselves. But, as with more complex terms like operationally responsive space, can we define it and pursue it, or is it simply something that we think we'll recognize when we see it? Do we even know what it really means?

Innovate comes from the Latin innovāre, further derived from the Latin in- (intensive) and novāre (to make new), so innovation is an intense effort to re-invent something. This aspect, *intensity of effort*, is what separates true innovation from mere product or process improvement. The latter generates marginal gains. The former drives revolutionary change.

Innovation is crucial to pushing back the boundaries of space exploration and utilization. But it exists in all aspects of human endeavor—across industries, cultures, and backgrounds. Innovation is both revolutionary and evolutionary. It changes not only the lens through which we view the world, but the very world we view through the lens. There is no doubt that attempts at innovation are ever-present, but results can be mixed at best. Which begs the question, what should innovation look like for the space industry? What "counts" as innovation? How can we, as an industry, harness the "intensity of effort to make new" required to deliver the technical progress and growth in capabilities that our customers demand?

Like a diamond in the rough, innovation has many facets. Each reflects, with varying brilliance, a valid approach. All contribute to the sparkle of the gem of innovation, but not all shine with the same intensity. And it is the "intensity of effort to make new"—the very roots and origin of the word—that is essential to achieve the kind of transformational changes now being sought in civil, commercial, and national security space.

The First Facet: Managed Progress – Innovation through Research, Programs, & Process Improvements

Independent research and development, directed research, total quality management, continuous quality improvement, Six Sigma—these are just a few examples of organizational, managed progress utilized by the space industry today. A product of the industrial revolution, these corporate and institutional process improvements have been defined and redefined to push industries toward innovation.

This type of "managed" innovation works at the margins, slowly aggregating progress. It is bureaucratic and corporation-speak, but is the foundation for evolutionary innovation. This is not the intense innovation that creates new technologies, but the innovation that leads to new uses of technologies or more efficient, more profitable production of technologies. This amounts to finding new ways to squeeze the lemon rather than finding new lemons to squeeze.

The Second Facet: Innovation through Passion and Persistence

In various turns, the entrepreneur or inventor is a type of innovator often called audacious, determined, delusional, crazy, or brilliant. These are the people who push the edge of the envelope doing what is deemed impossible. They are the individuals who, like Thomas Edison, believe with such intensity, they are willing to make 9,999 unsuccessful attempts before finally producing the first electric light bulb on the 10,000th. They are the entrepreneurs of yesterday, today, and tomorrow. This facet of innovation resulted in the wheel, electricity, the light bulb, the automobile, the airplane, the personal computer, modern rocketry, and so much more.

It is the passion—the *intensity*—of the inventor or the entrepreneur that drives this raw form of innovation. The amazing, awe-inspiring, and unbelievable leaps this type of innovator turns into reality are precisely why they MUST be encouraged by all possible means to participate fully in the exploration, development, and use of space.

The Third Facet: Unintended Consequences – Innovation through Exploration

The space industry is replete with examples of unintended consequences, of intentional innovation leading to amazing and unforeseen innovative technologies. Take for example cordless power tools, the DeBakey heart pump, medical imaging technology, satellite television, and the global positioning system. This is where most innovation takes place and where investments have the greatest ripple- or spiral-out effect. We set out to solve a problem or tackle a specific challenge by designing a new technology; once in hand, the technology reveals entirely new uses and applications. Entire new industries are born.

One of my favorite examples of this comes from Dr. Neil deGrasse Tyson's response to the question about the value in spinoff technologies: "Some will ask, why should we rely on spin-off products and technologies when we could just invest in the product itself? The problem is, innovation doesn't always work that way. For example, if you're the world's expert on thermodynamics, and I say, 'Build me a better oven,' you might invent a convection oven or one that's more insulated or one that's got better access to its contents. But no matter how much money I give you, you will not invent a microwave oven, because that comes from another place. It came from investments in communications, in radar. The klystron in microwave ovens is traceable to the war effort, not to some oven expert."[1]

This type of innovation is at the very heart of the space industry. Its pervasiveness and almost seamless integration into our daily lives is what makes the true reach of space innovation so difficult to accurately quantify. Though it is impossible to make an exhaustive count, it has been estimated that there have been more than 40,000 spin-off technologies from the space program. This begs the question—if we do not make the necessary investment in space today, what future unforeseen, life-altering technologies will we forego? What technologies and industries of the future will we simply allow other nations to develop and dominate?

The Fourth Facet: Innovate or Die – Innovation through Imperative

The imperative is competition. Why did we enter the space age? It was a National Security imperative. We had to innovate or we would fall behind the Soviet Union and lose the Cold War. Such high stakes (nuclear annihilation in the worst case, and at the very least the end of the American way of life if we lost) necessitated an *intensity of effort to make new*. At the beginning of our nation's space programs, "innovate or die" was literally a way of life. It was an underlying, unspoken mantra that pushed us to achieve the impossible. What is interesting is that today, in other industries, it remains an imperative. If you are a cell phone or computer chip manufacturer, you must bring a new product to market every 12 to 18 months, or your competitors will kill you. The telecommunication and information technology industries have a management mindset and organizational cultures that say "innovate or die."

Yet today, throughout the space industry, policy makers, appropriators, acquisition officials, and others have drifted toward a mindset of "don't screw this up." The fear of making mistakes has made us risk averse and drives from us the passion and sense of urgency required to achieve the *intensity of effort to make new* that is innovation. To make much-needed forward progress we need to change our organizational mindset and our culture throughout the national security space value chain from "don't screw this up" to "innovate or die."

The Fifth Facet: Integration and Collaboration

In aerospace, we all like to talk about the criticality of successful systems integration in our projects, programs, and products. Bringing together ideas, inventions, discoveries, technologies, and processes from all over the world is arguably the innovation equivalent of systems engineering. This Fifth Facet of Innovation is potentially the most powerful of all, and it is precisely what is threatened by the International Traffic in Arms Regulation (ITAR).

Throughout our industry there are remarkable examples of innovation and discovery enabled by the integration of ideas and technologies in collaborative efforts involving companies, governments, universities, national laboratories, and so on. For example, what amazing scientific discoveries and technological advances would we have missed out on without missions such as Cassini/Huygens and projects such as the International Space Station or the James Webb Space Telescope? Without this integration and collaboration, innovation is stifled and complex international missions are impossible. ITAR inhibits innovation by impeding our ability to collaborate with our friends and allies around the world. It erodes our access to intellectual and investment capital, technologies, complementary systems, and suppliers. ITAR impedes the ability of US-based space companies to compete in the international marketplace, which, in turn, erodes the industrial base that our national defense relies upon.

The collateral damage from ITAR is clear. US companies once commanded three-fourths of the global satellite manufacturing market, but today US market share is well below half. But this injury is just the tip of the iceberg. No longer able to depend upon US partners for components, technologies, or research, our foreign partners have been compelled to develop indigenous, non-US sources—in effect creating an autonomous, non-US-dependent global trade in space technologies. We are effectively forcing others to innovate without us and we are denying ourselves the ability to take a true, comprehensive systems engineering approach to innovation.

So What Does All of this Mean for the Space Industry?

Innovation by the space industry has led to technological advances and spin-offs that have transformed our lives and cultures to the point that it is impossible to imagine life without them. These innovations are often completely integrated into our everyday existence—such that we lose sight of where they originated, or that they are there at all. The benefits of our investment in space touch every aspect of life in the United States today. Our entry into space was the revolutionary innovation that changed the lens through which we see the world. The continued evolution of space technologies and capabilities has changed the world we see through that lens.

Sixty years ago there was no such thing as the "space industry." Space travel, space-enabled technology, and a space dependent society was the stuff of theory, dreams, fantasy, and science fiction. Today, they are very much a reality. In this short time, a fundamental shift in the way we live, transact commerce, and protect our Nation has occurred through space and from all five facets of innovation.

By investing in innovation in all its forms, we have become the world's leader in science and technology. However, our continued leadership is far from guaranteed.

"True innovation requires a bold vision supported by audacious investments in human capital," says Dr. Tyson.[2] A truer statement I cannot imagine. We must continue to drive innovation, to push the edge of the envelope in all five facets of innovation. Our leadership in the "high frontier" of space depends on it.

Notes:

[1] Dr. Neil deGrasse Tyson, keynote speech, National Space Club's Goddard Memorial Dinner, Washington, DC, 1 April 2005.

[2] Ibid.

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Prior to joining the Foundation, he was senior manager of public relations, employee communication, and advertising for all space programs of The Boeing Company.
Mr. Pulham is a member of the national board of advisors of the The Rotary National Award for Space Achievement Foundation, a member of the board of advisors of the National Institute of Science, Space and Security Centers and a member of the Chief of Staff of the US Air Force Civic Leader Advisory Group.

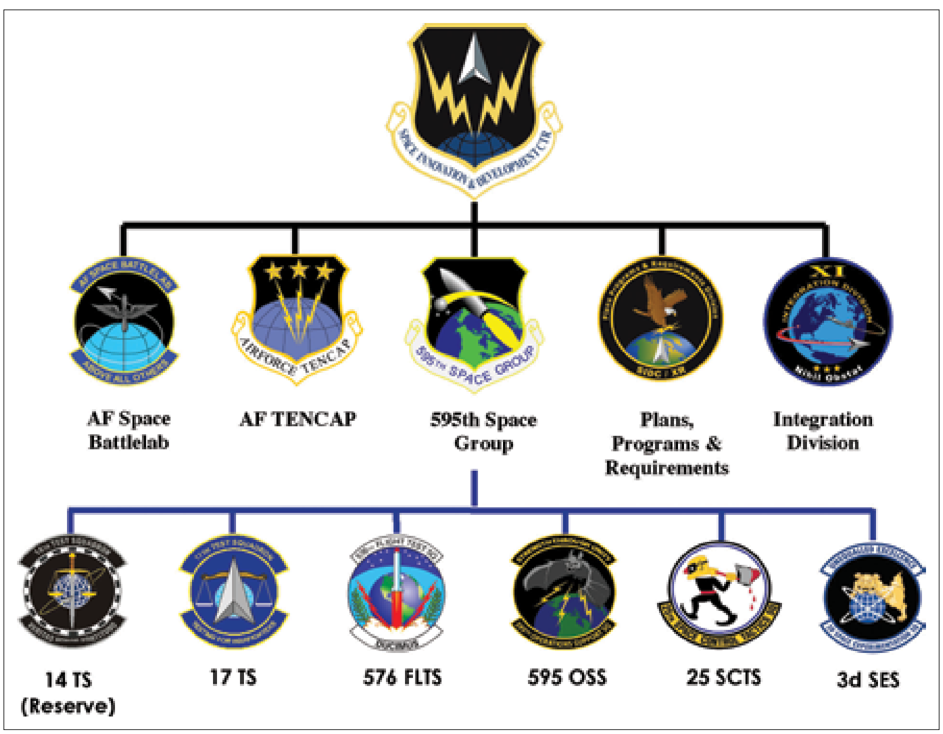
Space Innovation and Development Center "Unlocking the Potential"

Col Larry J. Chodzko
Commander
Space Innovation and Development Center

Mission: The mission of the Space Innovation and Development Center (SIDC) is to advance full-spectrum warfare through rapid innovation, integration, training, testing, and experimentation.

Vision: SIDC is "Unlocking the Potential" as the premier innovators, integrators, and operational testers of air, space, and cyberspace power to the warfighter.

As I near completion of my second year as commander of the Space Innovation and Development Center (SIDC), I look back with pride at our accomplishments. The SIDC has the most diverse blend of officers, enlisted, and civilians from air and space operations, communications, intelligence, engineering, and acquisitions that one will find in the Air Force. These experts rely on personal expertise, leveraging contacts from throughout their careers to address challenging issues facing the warfighting community. The SIDC is composed of two Air Force-level programs: Air Force Tactical Exploitation of National Capabilities (AF TENCAP) and the Air Force Space Battlelab (SB); two divisions: Plans, Programs, and Requirements Division (XR), and the Integration Division (XI); and, finally, the 595th Space Group. The following are some of the ways in which these units fulfill our mission every day:



Air Force Tactical Exploitation of National Capabilities

Through its 30 year history, AF TENCAP's objectives have remained consistent with congressional intent, and closely support the SIDC mission. AF TENCAP develops and demonstrates leading-edge space technologies with the potential to enhance combat capabilities of units in the field. It then transitions these combat systems to warfighters far more rapidly than traditional acquisition processes. AF TENCAP keeps current in the latest technologies and is tasked to influence emerging space systems to make them more supportive of fielded combat forces.

Two current projects, Talon NAMATH, and the Tactical High Altitude Externals Processor (THP), demonstrate commitment to the rapid acquisition of tools for the warfighter by leveraging existing National Technical Means.

Talon NAMATH is a global positioning system (GPS) enhancement that has increased combat strike precision via Web-based architecture for guided weapons. This program enabled the first-ever operational deployment of the small diameter bomb (SDB) to Central Command (CENTCOM) for combat use. The program increased overall SDB lethality using existing architectures while minimizing collateral damage to life and infrastructure. Talon NAMATH is a flagship example of how Air Force Space Command (AFSPC) can rapidly (18 months or less) enhance battlefield effectiveness at low overall cost.

THP enhances intelligence architecture by leveraging high speed processor technology to share tactical and national intelligence data with significantly higher speed and accuracy than previously possible. AF TENCAP has deployed THP to national agencies, CENTCOM Combined Air and Space Operations Center (CAOC), and Joint Task Forces. THP has improved our engaged forces ability to detect improvised explosive devices (IED) activities, while simultaneously improving the speed and accuracy over traditional signals intelligence detection. AF TENCAP continues to forge THP into national and operational CAOC "systems of record," enabling the Department of Defense (DoD) and intelligence community's vision of a global, open intelligence architecture capable of dynamic, near-real-time information exchange.

AF TENCAP is also developing tactical aircraft data protocols to enable increased national and tactical intelligence sharing.

AF TENCAP has been given oversight of two high-profile programs. The first is the US Air Force representative for the National Reconnaissance Office's Military Exploitation of Reconnaissance and Intelligence Technology program. This program fits "hand in glove" with the AF TENCAP charter from a national perspective. It is a joint service venue to leverage multiple sources of funding and work issues that are not unique to any one service. Additionally, AF TENCAP has been tasked to be the executive agent for AFSPC counter-IED efforts in response to an Air Force Chief of Staff (CSAF) mandate. The CSAF's mandate creates an IED Defeat Rapid Response Process to identify, coordinate, and facilitate the development of new capabilities to neutralize the IED threat.

Air Force Space Battlelab

The SB was created in 1997 as part of an CSAF initiative to bring responsive solutions to immediate warfighter needs. Its mission is to identify warfighter needs, develop innovations using existing technologies, and rapidly demonstrate the utility of those innovations in an operational environment. The mission of the SB is to transform space capabilities moulding existing technology into solutions for today's warfighting problems. By networking with industry, academia, and service laboratories, SB leverages leading-edge space technology to enhance Air Force core competencies.

The SB focuses on the most pressing operational problems and determines the best available solutions within existing technology. SB then produces a detailed campaign plan and demonstrates the effectiveness of a proposed solution in an operational environment. SB project managers use modeling and simulation, wargaming, exercise evaluations, and prototype demonstrations to quickly measure military value of promising concepts. Successful projects transition to other agencies for further refinement, or for deployment to the warfighter.

In an era of long acquisition cycles, the SB has a goal to evaluate and demonstrate ideas within 18 months, using a combination of tactics and/or commercially available technology. The SB selects projects using a value model based on "Warrior Outreach" surveys. The seven Air Force battlelabs participate in these Warrior Outreaches by visiting the Air Force major commands and interviewing the leadership on the most urgent needs. The SB's last Warrior Outreach was conducted at Headquarters, AFSPC (HQ AFSPC) in December 2006.

During the last year alone, SB managed 14 projects. A recent success is the Combat Hardened Aircraft Shelter Re-Radiation Demonstration (HASRD), which is the re-radiation of the GPS signal inside hardened aircraft shelters, allowing aircraft and weapons to be maintained without having to move them outside. This initiative is estimated to save Air Force flying wings 540 hours of maintenance per month. Another example is Combat Quiet Talk, which is a portable system providing inexpensive, secure voice and data capability over the Iridium satellite system. This system is a Joint effort with Air Mobility Command to provide their aircrews with communication capabilities around the world, whether airborne or on the ground.

Plans, Programs, and Requirements

XR is the backbone of the organization, providing overarching support to all other SIDC divisions. XR manages communications and computers, security, acquisition, logistics, policy, planning, programming, financial support, manpower, and personnel. XR is the commander's authority on reviewing, coordinating, and consolidating all SIDC inputs to AFSPC/A8/9's Modernization Planning Process and AFSPC/A5's associated Requirements Generation System. XR also serves as the representative for the CSAF's Air Force Smart Operations for the 21st century initiatives. As the lead SIDC programming and requirements agency, XR integrates our views and initiatives into these AFSPC-level programming systems to solve warfighter deficiencies through space capabilities. As SIDC's executive agent for submitting Program Objective Memorandum inputs, XR develops strategy, policy, doctrine, and long-range plans to control and exploit space. XR programs and advocates manpower, resources, and organizational development for long-term success of our mission.

Integration Division

XI brings space to the fight by focusing on the integration of air, space, and information operations to create aerospace power for warfighters. Within XI, the Distributed Mission Operations Center—Space (DMOC-S) provides space support and capabilities to exercises. Essentially, the DMOC-S exercises operational plans, machine to machine interfaces to present status to players as if it were real world and space injects such as missile launches, blue force tracking data and Combat Search and Rescue.

I recently challenged the DMOC-S to fully engage with Red Flag Alaska. The vision set forth for the exercise is to build a realistic, all-domain, Joint range to train 21st century forces in Joint and combined combat operation from tactical through operational levels of war. This challenge presents a unique opportunity to demonstrate the benefits of an integrated air, space, and information operations Joint training environment. Future wars will not be fought in one domain, but instead will be fought across the entire spectrum of air, space, and information operations. Thus, we need to train our operators appropriately to deal with these challenges.

Another XI function, the Aerospace Fusion Center (AFC), provides real-time data fusion systems for targeting, intelligence, weapons of mass destruction warning, and enhanced missile defense operations. From the 1993 Talon SHIELD inception to the current leader in non-traditional, Overhead, Non-imaging Infrared (ONIR) fusion, and all-source correlation, the AFC has steadily broadened its tool chest.

Recently, AFC engineers decided to take a closer look at ONIR analysis. Weaknesses in technologically ancient satellites were completely overshadowed when attacked by modern data mining techniques. Once again, data that was previously dropped or ignored was discovered to hold a treasure trove of information. It took time to see what tale non-imaging sensors would spin.

The fundamental advantage for the AFC is persistence, the ability for the satellites to view full-pan at low resolution, compared to modern, technically superb sensors which traded high-resolution for narrow field of view. Following a six-month effort, trends and indicators began to emerge. These results fit squarely within the four components of space situational awareness (SSA): intelligence, surveillance, reconnaissance, and environmental monitoring. The result for HQ AFSPC is that traditional systems are tracking many targets, in addition to missiles.

Our latest development is the Space Awareness and Global Exploitation (SAGE) mission system. SAGE is specifically designed to capture rapid advancements and emerging capabilities. A SAGE demonstration correlating National Aeronautics and Space Administration's Aqua and Terra, multi-spectral satellite data has shown great promise for differentiating dim targets from bright backgrounds. Breakthroughs in non-traditional processes and techniques reside on SAGE and are capable of transitioning to warning squadrons and warfighting centers. The AFC continues to maintain AFSPC superiority through flexible and technically superior research as a development center focused on creating new tools and techniques.

XI also leads the Schriever Wargame team to promote the understanding and effective use of space power through modeling, simulation, and analysis. The team has since planned and conducted Schriever I, II, and III. These focused on space and space-related contributions to the warfighting capabilities of the US and its allies. The latest in the series, Schriever IV (S-IV), occurred in late-March 2007. This wargame is focused on exploiting future space capabilities along with exploring new concepts for operating those systems in future conflicts. S-IV provides a unique opportunity to investigate future space systems and the missions they support, and explores how to ensure their survivability.

The Schriever wargames are a means to explore ways to mature the integration of air and space into a single fighting force capable of bringing immediate space-based effects to warfighters. They investigate how space-based assets can be used in homeland defense to build and sustain a cadre of space professionals fluent in space issues and focused on the needs of warfighters.

595th Space Group

The 595 SG is responsible for planning, managing, and executing AFSPC's intercontinental ballistic missile (ICBM) and space systems operational test and evaluation activities. The 595 SG is the focal point for coordinating all test activities between HQ AFSPC, 14 AF, 20 AF, space wings, test squadrons, and external agencies. 595 SG is composed of six squadrons:

595th Operations Support Squadron (595 OSS): The 595 OSS enhances air and space force readiness by providing operations and intelligence expertise to the space and missile test, training, tactics development, experimentation, and intelligence missions of the SIDC.

The 595 OSS currently has many of its active-duty members deployed in support of Operations Enduring Freedom and Iraqi Freedom. Personnel work programs within AF TENCAP and the SB to help solve theater problems in countering improved explosive devices, targeting and tracking terrorists and foreign fighters, and utilizing advanced communication and navigation techniques. The efforts of the professionals within the OSS continue to positively contribute to fighting and winning the Global War on Terrorism (GWOT).

17th Test Squadron (17 TS) and 14th Test Squadron (14 TS): The 17 TS validates and enhances warfighter capabilities through testing and evaluation of space systems. The 17 TS, along with it's reserve component the 14 TS, is responsible for planning, executing, and reporting on all force development evaluation, tactics and concepts testing, and command-directed testing of AFSPC's space assets. The squadron's vision is to be recognized and respected as the premier test experts providing operationally-relevant testing of space systems. As major command testers for AFSPC, the 17 TS independently evaluates space systems' ability to meet required operational capabilities and ensures space capabilities are delivered to the warfighter in an expedient manner.

The 17 TS independent test capability is best exemplified by their support of the fast track AF TENCAP initiative, Talon NAMATH, which provides GPS navigation data via Link 16 to Air Combat Command (ACC) platforms. Through a multi-command collaborative effort with ACC's 46th Test Squadron, the 17 TS tested at four geographically-separated locations 24/7 over a five-day period. The exceptional work of the test team confirmed Talon NAMATH improves GPS accuracy by 25 percent and reduces variations in reported position by 50 percent. The entire testing process, from test order to final test report, was completed in an unprecedented 57 days. The successful assessment of Talon NAMATH enabled rapid fielding to the theater to enhance small diameter bomb accuracy for use in support of the GWOT.

576th Flight Test Squadron (576 FLTS): The 576 FLTS, located at Vandenberg AFB, California, executes the Joint Chiefs of Staff-directed ICBM Force Development Evaluation test program and executes AFSPC's operational tests for the DoD. The 576 FLTS performs ground, flight, and space system tests in operationally representative environments and collects, analyzes and reports performance accuracy, anomaly assessment, reliability, aging, and surveillance data to the Joint Staff, Air Staff, US Strategic Command and other higher headquarters.

Over the life of the Minuteman Weapon system, there has been continuous improvement as a direct result of the on-going

The Schriever wargames are a means to explore ways to mature the integration of air and space into a single fighting force capable of bringing immediate space-based effects to warfighters.

Force Development and Evaluation (FDE) testing performed by the 576 FLTS. In fact, testing, and the resulting changes have significantly improved the capability of the ICBM force. Tests conducted by the 576 FLTS have resulted in numerous improvements to the system. The deficiencies required material improvements such as redesigned parts and components; accelerated field or depot-level maintenance; and improved screening procedures by manufacturers allowing for identification and repair prior to delivery to the Air Force.

FDE testing has also corrected numerous issues that had the potential to cause in-flight failure, using non-material solutions. These non-material solutions are, most commonly, ICBM technical order changes that improve the conduct of ICBM maintenance and operations through more comprehensive inspections or procedural changes that preclude creating undetectable damage capable of causing a critical failure.

The 576 FLTS dramatically improved testing by the integration of operations and maintenance in the squadron, and the more recent assumption of all maintenance tasks for operational test launches. While operational test launch maintenance was previously performed by a task force deployed from the missile's operational unit, through a lean initiative, we eliminated the need for the task force without any increase in squadron manpower. It was already required to conduct test unique activities (command destruct, telemetry, and tracking systems installation and checkout), in addition to day-to-day maintenance requirements for facilities and equipment when the task force was not on station. The 576 FLTS use of integrated operations and maintenance test teams allowed us to expand our testing efforts and evaluate, in concert with 20 AF and HQ AFSPC, the maintenance suitability of improvements to ICBM ground systems and support equipment such as the new fast rising B-plug and the payload transporter security upgrade.

25th Space Control Tactics Squadron (25 SCTS): The 25 SCTS is responsible for the operation of the Space Test and Training Range, a capability that allows units to exercise space capabilities in a safe, secure, and realistic environment while eliminating the risk of unintended collateral effects. The 25 SCTS owns the Advanced Concepts Environment, which simulates a target, weapon system, and environment for training and rapid reaction prototype development.

3d Space Experimentation Squadron (3 SES): The 3 SES is AFSPC's premier organization for space-based demonstrations, pathfinders, and experiments. The unit identifies concepts of employment, training, education, and technical skill sets required to field selected future AFSPC missions. The 3 SES will develop a core cadre of space professionals to serve as subject matter experts for all future AFSPC space-based endeavors, demonstrate operational utility of selected demonstrations, and apply lessons learned from demonstrations and pathfinders for use in future initiatives.

Through this short treatise my hope is that you have gained a greater understanding of the role the SIDC plays in National Defense. Recent events have shown that we are facing adversaries that employ both traditional and non-traditional means to attack us. Our enemies have proven themselves to be resilient and capable of rapidly changing their tactics to inflict damage. The key in defeating them is to be even more rapid in employing our counter-measures be it a materiel, tactics, or training solutions. The SIDC is at the forefront of winning this war since we are uniquely positioned to affect the full spectrum of warfare through rapid innovation, integration, training, testing, and experimentation.

Col Larry J. Chodzko (BS, Psychology, University of Illinois at Chicago; MS, Operations Management, University of Arkansas at Fayetteville) is the commander, Space Innovation and Development Center, Schriever AFB, Colorado. The Space Innovation and Development Center is the centerpiece of the Air Force Space Command's efforts to fully integrate space into the daily operational Air Force. The center develops new techniques and procedures to apply space-based capabilities to military training, exercises, plans, and operations in support of Department of Defense front-line warfighters. Colonel Chodzko also provides oversight of the Air Force Tactical Exploitation of National Capabilities and Air Force Space Battlelab programs.

Colonel Chodzko is a master navigator with more than 4,000 flight hours in C-130 A, B, E/H aircraft.

The Colonel deployed in support of several major contingencies; including Operation Provide Promise, Operation Deny Flight, the Air War Over Serbia, Operation Uphold Democracy, Operation Enduring Freedom, and Operation Iraqi Freedom.

His initial assignment was instructor navigator at Clark AB, Philippines. He was then assigned to Little Rock AFB, Arkansas as chief of squadron Stan/Eval. From there his assignments included: Scott AFB, Illinois as chief of Combat Tactics-Space Warfare, Falcon AFB, Colorado as flight commander and then chief Mission Support, AF Space Team, Vandenberg AFB, California as 14 AF chief of Weapons and Tactics, Scott AFB as chief of Aerospace Integration Branch, deputy chief of Combat Operations Division and then chief of Combat Operations Division, Schriever AFB, Colorado as vice commander of the Space Warfare Center and then as commander of the Space Innovation and Development Center.

Among his many awards, Colonel Chodzko has been awarded the Meritorious Service medal with three oak leaf clusters, Air Medal with one oak leaf cluster, Air Force Commendation Medal and the Air Force Achievement Medal.

Space Superiority – Enabled by High Risk High Payoff Technologies

Dr. B. "Babu" Singaraju, Dr. Tom Caudill,
Dr. Nathan Dalrymple
Air Force Research Laboratory
Space Vehicles Directorate

The United States is critically dependent on space capabilities in peace and war. The asymmetric advantage we enjoy in space capabilities is a result of an enabled technology base and concepts that have been experimentally proven in space. Air Force Research Laboratory (AFRL), as the technology arm of the Air Force, has been at the forefront in developing and demonstrating technologies that enable these space capabilities. In this paper we will discuss some of these technologies we are developing and demonstrating to ensure our continued asymmetric advantage in the future.

Introduction

Space assets have become indispensable for national security and commerce of the United States. Capabilities we have grown accustomed to, for example, are worldwide communications, surveillance, weather, and position, navigation, and timing. All of these have become central to our warfighting capabilities, from weapons delivery to providing real time contact with the front line forces. Indeed, space capabilities are no longer just a support function, but are in the fight. Quadrennial Defense Review (QDR) of 2006 recognized this fact and asserts: "The Department will continue to develop responsive space capabilities in order to keep access to space unfettered, reliable, and secure. Survivability of space capabilities will be assured by improving space situational awareness (SSA) and protection, and through other space control measures. …"[1] Space capabilities not only add to America's already far superior conventional fighting power, but are central to a fully integrated aerospace capability.

Challenges we face for the future are well articulated in the QDR and consist of: (1) defeating terrorist networks, (2) defending homeland in depth, (3) shaping the choices of countries at strategic crossroads and (4) Preventing hostile states and non-state actors from acquiring or using Weapons of Mass Destruction (WMDs) as depicted in figure 1.[2]

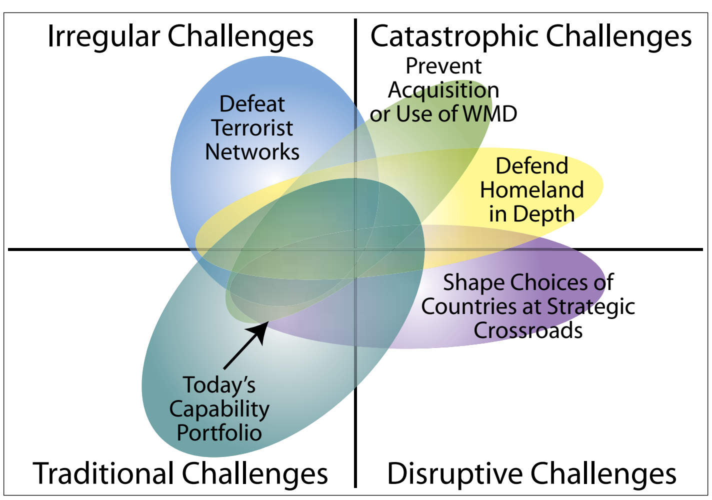


Figure 1. Shifting portfolio of capabilities by Department of Defense.

AFRL, the technology arm of the Air Force, has been adjusting its portfolio to meet these new needs in the changing environment.

AFRL Strategy

AFRL has been responding to these national policies with enabling technology investments in: space superiority; operationally responsive space; intelligence, surveillance, and reconnaissance (ISR); and command, control, and communications (C3). Strategic objectives of these technology developments and transition goals we established are for:

- Space Superiority
  - Freedom to conduct operations without natural or man made interference
- Responsive Space (RS)
  - $30 million mission, operational one week from call up, tasked from field
- Advanced ISR
  - Ability to assess anything, anytime, anywhere
- Expanded C3 Technology and Applications
  - Address Global Information Grid and Joint Battlespace Infosphere objectives
  - Pervasive integration of communications; space superiority; and rapid, low-cost space access

These strategic goals require that AFRL support near term system acquisitions with technologies that buy down the risk, and longer term high risk/high payoff technologies that are game changing capabilities that are not currently envisioned. These capabilities are intended to support the full range of future conflicts while leading the world in space supremacy research and development. Major strategic emphases of these AFRL technology investments are to reduce the cost of ownership and to provide responsive and highly capable systems.

Overview of Technology Investment Areas

US National Space Policy (NSP) has recognized the importance of technology and sets one of its goals to "Enable a robust science and technology [S&T] base supporting national security, homeland security, and civil space activities …"[3] In keeping with this national policy, AFRL has been investing in a panoply of technologies that will enable future capabilities.

A short list of technology thrusts in each of the emphasis areas are:

Space Situational Awareness

- Miniaturized space weather sensors

- Advanced coupled space weather models
- High-fidelity sensing

Defensive Counterspace (DCS)

- Passive countermeasures
- Defensive reaction

Responsive Space

- Rapidly respond to unanticipated threats
- Rapid augmentation and replenishment

Command, Control, and Communications

- Transformational communications
- Space operations command and control (C2)

Intelligence, Surveillance, and Reconnaissance

- All weather, day/night sensing
- Persistent moving target indicator
- Global missile warning/defense
- Hard to find targets

In the rest of this article, we will concentrate on technologies necessary to enable and enhance space superiority.

Space Superiority

Space superiority, some times called space control, consists of SSA, DCS and offensive counterspace (OCS). NSP is very clear on space superiority: "United States considers space capabilities—including the ground and space segments and supporting links—vital to its national interests. Consistent with this policy, the United States will: preserve its rights, capabilities, freedom of action in space; dissuade or deter others from either impeding those rights or developing capabilities intended to do so; takes those actions necessary to protect its space capabilities; respond to interfere; and deny, if necessary, adversaries the use of space capabilities hostile to US national interests."[4] Shown in figure 2 is the inter-relationship between various elements of space superiority. SSA, DCS, and OCS are not mutually exclusive elements, but rather are very interdependent. In the rest of this article, we will discuss the advanced technology efforts underway in the SSA and DCS areas.

Space Situational Awareness

The first requirement to maintain space superiority is SSA. SSA forms the foundation for all space operations. The overarching goal of SSA is to provide the nation with the ability to find, track, identify, and characterize all space objects. Another aspect is to specify the space environment, forecast upsets and damage to space systems, and differentiate between environmental damage from those due to attack.

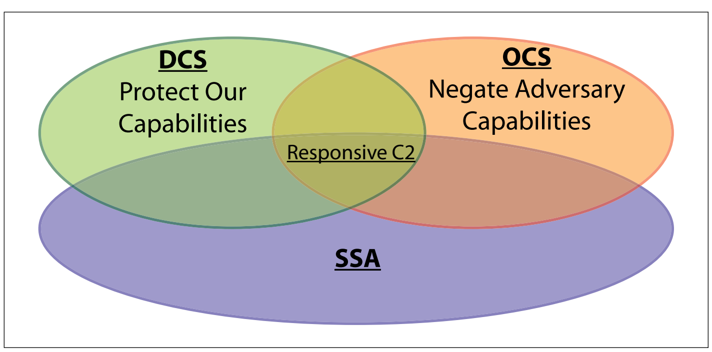


Figure 2. Inter-relationships between elements of space superiority.

At a time when the number of objects in space is increasing, advanced technology enables the size of spacecraft to get smaller which is creating challenges for current tracking systems designed during the Cold War. In addition, we only have a minimal characterization capability at present. This means that there are more objects, dimmer objects, more maneuverable objects, satellites with a wider range or capabilities, as well as a requirement for space weather prediction which drive the need for improved SSA capabilities. These new capabilities drive the technological challenges for SSA to provide more sensitive sensors with wider fields of view, to explore the use of our own small/nano-satellites, and to develop a more robust space environment forecast capability.

Space systems will use tailored passive sensing systems to accomplish the mission of SSA. Superiority demands the best performance, even combining functions within a single pixel of a SSA sensor focal plane. Within the SSA portfolio we are developing technologies to provide wide field-of-view sensors for surveying large areas of the sky, autonomously integrating data, detecting patterns/anomalies, and classifying space objects. The technologies that support this include space qualified, high-sensitivity, large-format focal plane arrays (FPAs); large light-weight optics and an understanding of space object signatures for a variety of new phenomenologies. In this area we have a number of efforts that support current programs, such as the Space Based Surveillance System, as well as developing new technologies to enhance or enable future systems. FPA developments in longwave infrared that are tailored for midcourse surveillance of ballistic missiles, reentry vehicles, and decoys, may be able to be leveraged to answer the need for sensing of space objects. We are also working to make visible focal planes more radiation tolerant. The long-term goal of this area is to provide a cost-effective system of small satellites to provide continuous surveillance of all objects in orbit. These technology developments also include Air Force Office of Scientific Research (AFOSR) sponsored work to perform multiple sensing functions in combined fashion.

We are also exploring technologies to provide high-fidelity characterization of space objects. The in-house technology development portfolio concentrates on electro-optical (EO) systems but we are collaborating with other organizations on non-EO technologies. The Experimental Satellite System-11 (XSS-11) demonstrated technologies for autonomous operations around resident space objects. The Autonomous Nano-satellite Guardian for the Evaluating Local Space (ANGELS) (figure 3) effort will build upon that knowledge to enable future capabilities. Other facets of the effort are in phenomenology understanding, nanosatellite development, and lightweight optics. The long-term goal of this area is to provide 24-hour, on-demand, affordable, ultrahigh-fidelity characteriza-

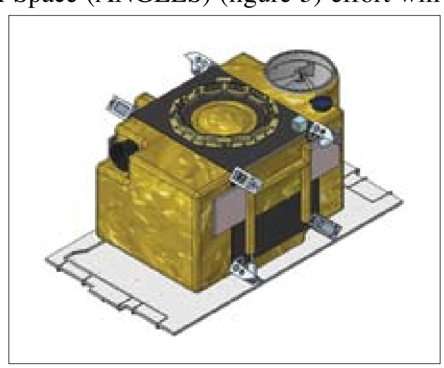


Figure 3. Autonomous Nano-satellite Guardian for the Evaluating Local Space.

tion out to very long stand-off distances.

The space environmental research looks at how space weather affects both the operation of space assets and their ability to perform their missions. Space weather impacts on satellite operations include the occurrence of single event upsets (SEUs) to electronics, radiation dose damage to spacecraft electronics, spacecraft charging and discharging, and orbital drag. Satellite anomalies may be due to any of three vastly different causes: an engineering failure, an environmental event, or a deliberate attack. It is critical to be able to quickly determine whether the environment had an impact before suspecting an attack. Another equally important impact is that ionospheric turbulence leads to fluctuations in electron density that cause communication links to scintillate (fade or total disruption). The long-term goal is to provide accurate atmospheric specification and 72-120 hour forecast tools for space operators and users to mitigate/exploit space weather phenomena.

Space weather is a pervasive research area touching a broad variety of Department of Defense (DoD) missions, including communication and navigation, C2, ISR, and SSA. The physical phenomena that lead to effects in these mission areas are also diverse and include time and length scales from micro to astronomical. Progress towards measuring, understanding, modeling, and ultimately mitigating the effects of the space environment requires expertise in plasma physics, chemistry, electrodynamics, fluid mechanics, solid state physics, electronics engineering, and radiative transfer.

There are significant and considerable gaps between the current state-of-the-science of space weather and the needs of the operational Air Force. Air Force Space Command's (AFSPC) top priorities in space environmental effects characterization include: scintillation effects on satellite communication (SATCOM), solar radio frequency interference on SATCOM, deep dielectric charging/discharging and single event effects on satellite operations, orbital drag forecasts, and total radiation dose accumulation on satellites. Current capabilities in these areas vary from weak to moderate, depending on the specific need, but in general there are three major areas for improvement: (1) Increasing the amount of observations and data on the space environment, (2) understanding the physical phenomena to a level where accurate predictive models can be developed, and (3) quantifying the effects of the space environment on systems so that compensation and/or mitigation techniques can be applied.

Turbulence in the ionosphere leads to fluctuations in electron density over time and length scales that cause communication links to scintillate. This scintillation can be severe enough to disrupt communication through the ionosphere. The impact of scintillation on SATCOM links is AFSPC's number one space environment priority. Possibly even more significantly, the impact on global positioning systems is pervasive across many activities, not the least of which is getting precision guided munitions on target. Our current understanding of the existence of turbulent plasma bubbles in the ionosphere is based on limited observations primarily from ground-based incoherent scatter radars and networks of scintillation monitors, including those associated with AFRL's Scintillation Network Decision Aid. The physics associated with the development and dynamics of these bubbles is just beginning to emerge and involves complex interactions between the mesosphere, ionosphere, and thermosphere. As with many aspects of space weather, the ultimate source of energy is the Sun, so in order to predict scintillation an understanding of solar and solar wind activity is necessary.

Space weather impacts on satellite operations include the occurrence of SEUs to microelectronics, radiation dose damage to spacecraft, surface and deep dielectric charging/discharging, and orbital drag due to variations in the height and composition of the neutral atmosphere at satellite altitudes. Research in the sources and nature of solar energetic particles, propagating disturbances in the solar wind, the development and decay of radiation belts, and the dynamics of the thermosphere is crucial in this mission area. Quantitative modeling of the effects of energetic particles and radiation on spacecraft subsystems is ongoing, as well as research toward developing distributed sensors that can be integrated on a spacecraft to actively monitor environmental effects.

Although implicit in all of the preceding areas, there is a need to conduct routine environmental monitoring (EM) to provide complete SSA capability. As with terrestrial meteorology, in order to effectively impact the decisions of combatant commanders as well as system engineers, a comprehensive picture of the conditions of the space environment is crucial. EM of space starts below the surface of the sun and extends through the heliosphere, magnetosphere, thermosphere, and ionosphere. Given the vastness and remoteness of space, and the expense of in-situ sensors, careful thought must be applied to this problem. It is an exercise to determine the most important parameters to monitor, as well as to design miniaturized sensors and techniques for utilizing existing systems for this purpose.

Defensive Counterspace

The vision of AFRL's DSC technical area is to "ensure continued US freedom of action in space: Developing technology responsive to the emerging threat." We are partners with the US space community in this vision and are developing S&T to assure that the Air Force, US National, and other friendly space systems will continue providing essential space services by protecting against natural and manmade threats in the full conflict spectrum from peace through war. Within the space superiority construct, the DCS technical area is a primary partner with the SSA and counterspace studies area and depends heavily upon the C2 technical area to ensure that DCS functionality can be effectively employed.

We are giving increased emphasis to this area as a result of recent information indicating an acceleration of the threat. We carefully choose which S&T opportunities to pursue within our resource constraints by balancing other organization protection efforts while considering the likely and stressing near term threats and the potential emerging threats to our space systems. Two recent, AFRL Space Vehicles Directorate-led, community-wide studies have focused DCS AFRL technology investment options to address the key threats; Space Vehicles Directorate has used these study priorities to guide our current investments. These threats encompass the spectrum of adversary's capabilities that can be envisioned. In this article, we will concentrate on the technologies to protect our space systems against natural and nuclear enhanced space environments.

Electronics are clearly central to this protection strategy. Over time we have arrived at a functional arrangement for our electronics program that focuses on critical research phases and interactions that maximize breakthrough developments and minimize the transition time to the warfighter:

- ***Foundations.*** Basic research (new device/design concepts, materials, fabrication techniques), holistic approaches to "radiation hardness" (minimally-invasive techniques and system-level strategies to mitigate radiation effects), new strategies for qualifying microelectronics as flightworthy, and an eye toward game-changing advances in nanoscale technologies;
- ***Components.*** Develop/evaluate critical components (e.g., processors, memories, structured/reconfigurable gate array fabrics) required for current and future DoD space systems;
- ***Systems.*** Explore/evaluate logical and physical architectures, innovate/exploit break-throughs in packaging, self-organization, and reconfigurability.

Using that technical structure, our electronics program focuses a small team of exceptionally skilled scientists and engineers on leading-edge research, development, demonstration, and transition of high-performance, low-power, radiation-resistant electronics and microsystems.

Since space missions, as well as their protection are enabled by electronics, the Next-Generation Space Electronics program addresses survivable commodity electronics (e.g., memories, field programmable gate arrays, processors, structured application-specific integrated circuits [ASICs]) and augments DCS strategies through on-board processing and self-describing component interfaces to both simplify and empower the design of DCS architectures. These strategies will allow rapid integration of new protection components without redesign of platform hardware/software. During the past two years the DCS technical area counts significant accomplishments. We will highlight the Next-Generation Space Electronics program, which has delivered circuit test chips of radiation hardened field programmable gate arrays that reduce design costs by 60 percent as compared to standard integrated circuit development, produced a prototype radiation-hard non-volatile memory (retains data even after an interruption of power), and advanced structured ASICs as a high-performance, low-cost approach to space electronics.

Increasingly sophisticated military space capabilities demand ever more capable space electronics. Without them, images cannot be processed, messages cannot be delivered, and global reach is impossible. The demands of defense space systems ("immune" to radiation, extreme reliability, etc.) preclude the use of commercial off-the-shelf (COTS) electronics. These requirements mean defense space electronics performance typically lag COTS electronics. Our key objective is to focus the nation's S&T excellence on overcoming these challenges, and develop the most secure, highest performance, most reliable electronics for defense space systems.

There are primarily two organizations that invest in defense space electronics S&T, AFRL and the Defense Threat Reduction Agency (DTRA). The roles of these two organizations are complementary and coordinated through frequent direct interaction. AFRL, through AFOSR, directs the vast majority of the basic research that develops the scientific knowledge needed to develop highly-advanced future generations of space electronics. Our applied research programs develop design and process techniques to enhance the hardness and reliability of space electronics while the DTRA applied research investments develop and insert radiation hardening technology into the industrial base. The AFRL space electronics development program then exploits and extends the applied research products and the industrial base capabilities to design and develop high-performance defense space electronic components. The AFRL program is renowned for developing numerous key spacecraft components—practically every DoD satellite uses these components (e.g., RH-32, GVSC, Rad 6000) (figure 4), as do non-DoD space missions such as the Mars Rovers.

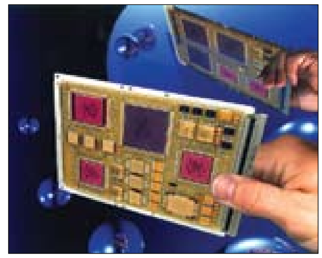


Figure 4. Rad 6000 Processor.

It is ever more important in this era of growing budgetary pressures to develop the right technologies—the ones most essential to the warfighter. We have recently initiated a new technology planning process to offer the warfighter a bigger bang for their buck. The process begins with modeling and analysis of key functional requirements (performance, size/weight/power, hardness, reliability, etc.) for specific mission types (e.g., ISR, communications, space superiority, missile defense, etc.). We obtain space electronics' requirements by combining these analyses with inputs from the Office of the Secretary of Defense's Radiation Hardened Electronics Oversight Council, AFSPC, System Program Offices, space system prime/sub contractors, and others. This methodology provides a more rigorous connectivity to warfighter needs and helps us communicate the important relations of individual projects and entire development areas to users/customers.

Although requirements identify destinations, the paths taken to get there are dictated by important technical considerations. Our technical program deals with important trends in electronics: decreased feature size, decreased size/weight/power, improved scalability and flexibility, increased integration of multiple domains (analog, digital, microwave, and power) into "systems-on-a-chip," and improved reliability (including radiation hardness). In addition, our program deals with important trends in systems: flexibility, affordability, scalability, and building very complex systems as rapidly as possible. To do this, we must understand the nature of complex systems and networks, the things that give rise to time delays and cost in developing these systems. We then apply scientific methods to develop not just the best-performing electronics but to yield them rapidly and affordably.

In summary, this strategically planned DCS program is:

- Driven by vision and innovation
- Traceable to documented and derived customer needs
- Leading other DoD programs via coordination/cooperation
- Exploiting existing/planned commercial developments
- Effectively using resources (world-renowned S&Es, unique facilities, and funding)

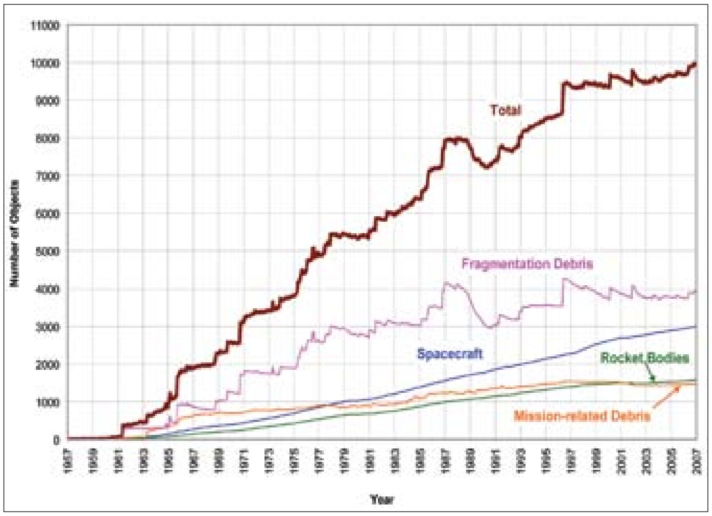


Figure 5. Monthly number of cataloged objects in Earth orbit by object type.

Summary

Space superiority is a vital part of the warfighting capability of the United States. We are critically dependent upon space capabilities in peace and war. The asymmetric advantage space capabilities have afforded us has not gone unnoticed by friend or foe. Countries around the world are ever increasing their space capabilities while at the same time they are potentially developing capabilities to deny our use of space. Technology has been the key that has given us the advantage we have in space and continued technology superiority will be the key in maintaining our space superiority.

"Fifty years ago, Mao Zedong lamented that China could not even launch a potato into space. Now it has succeeded in hitting a weather satellite more than 800km (500miles) above earth with a ballistic missile fired from the ground".[5] "China is likely to continue making large investments in high-end, asymmetric military capabilities, emphasizing electronic and cyber-warfare; counterspace operations; ballistic and cruise missiles; advanced integrated air defense systems …"[6] Indeed the world has changed over the last fifty years. The number of countries with space capabilities is increasing dramatically, coupling that with the increasing threats to our space capabilities, requires us to be ever vigilant. The number of objects in space is increasing at an almost exponential rate (figure 5),[7] while the number of launches of small satellites by countries around the world is also increasing dramatically (figure 6). These evolving capabilities, by friend and foe alike, demand that we continue to develop and demonstrate new technologies for space superiority—the ultimate high ground.

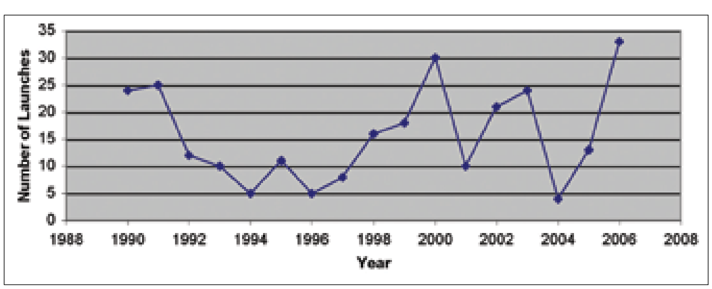


Figure 6. Number of small microsatellite launches.

Notes:

[1] Donald Rumsfeld, secretary of defense, *Quadrennial Defense Review Report* (Washington, DC: Department of Defense, 6 February 2006), hereafter cited as the *QDR Report*.

[2] Ibid.

[3] *US National Space Policy*, fact sheet, White House, US Office of Science and Technology Policy, released October 2006, www.ostp.gov/html/US%20National%20Space%20Policy.pdf (accessed on 18 March 2007).

[4] Ibid.

[5] "China's anti-satellite test," *The Economist*, 25 January 2007, 38-42.

[6] *QDR Report*.

[7] *NASA Orbital Debris Quarterly News* 11, no. 1 (January 2007), NASA Johnson Space Center, figure 5 graph, 8.

Dr. "Babu" Singaraju (BS, MS, and PhD, Electrical Engineering, with specialization in Electromagnetics, New Mexico State University and National Research Council Associate Post-Doctorial Research at Air Force Weapons Laboratory) is the technology area lead for Counterspace Studies at the Air Force Research Laboratory, Kirtland AFB, New Mexico.

He serves as the deputy for Under Secretary of Air Force Vector III for "Freedom to Operate in Space." He served on Air Force Scientific Advisory Board that developed long range investment strategy for future space investments.

Dr. Singaraju co-authored book chapters *Electromagnetics and Responsive Space*. He has authored over 75 reports and papers in peer reviewed journals and delivered over 70 presentations at peer reviewed technical conferences. He is an elected Fellow of the American Institute of Aeronautics and Astronautics; Senior Member of the Institute of Electrical and Electronics Engineers; Elected Member of ETA KAPPA NU Electrical Engineering Honor Society; Elected Member of SIGMA XI Research Honor Society; and recipient of numerous civil service awards.

Dr. Thomas R. Caudill (BA, Chemistry, University of Colorado; MS and PhD, Atmospheric Physics, University of Arizona) is the Space Vehicles (VS) directorate technical area lead for Space Situational Awareness (SSA). This includes the oversight and technical management of the entire SSA portfolio in VS and requires significant coordination with other AFRL directorates and outside organizations. Previously he was the chief of the Space-based Infrared Technology Branch, which works on many aspects of space-based remote sensing including focal planes, cryocoolers, and other advanced sensing technologies. He has been involved at both the technical and management levels on a variety of theoretical and experimental projects. This work included hyperspectral remote sensing where he was the principal investigator for the Fourier Transform Hyperspectral Imager on the MightySat II.1 satellite.

Dr. Nathan E. Dalrymple (BS and MS, Mechanical Engineering, University of Houston; PhD, Nuclear Engineering, MIT's Plasma Science and Fusion Center) is the Defensive Counterspace technical area lead at AFRL/VS. As the DCS lead, he manages an annual science and technology research portfolio of about $40 million.

Previously Dr. Dalrymple worked for the Air Force Research Laboratory (AFRL) National Solar Observatory in Sunspot, New Mexico. At Sunspot, Dr. Dalrymple developed optical systems for the study of solar plasma physics and space weather drivers and eventually became program manager for AFRL's Solar Disturbance Prediction program.

NASA's Innovative Partnerships Program: Matching Technology Needs with Technology Capabilities

Mr. Douglas A. Comstock
Director, Innovative Partnerships Program,
National Aeronautics and Space Administration

In the pursuit of mission objectives in aeronautics and space exploration, the National Aeronautics and Space Administration (NASA) is often pushing the boundaries of what has been done before, needing many technologies to either enhance current capabilities or enable new capabilities. NASA's administrator, Michael Griffin, told the World Economic Forum on 26 January 2007, that "Necessity is the mother of invention, and I believe that we are at our most creative when we embark on bold ventures like the space program."

As a result of the technical advances needed to achieve those ventures, NASA missions often generate technologies which have applications beyond aerospace and can provide important benefits to improve the quality of life for the American public. As NASA's deputy administrator, Shana Dale, said at the 2nd American Institute of Aeronautics and Astronautics Space Exploration Conference on 5 December 2006, "Of course, much of what we gain from exploring and settling the Moon will not be in what we find on it, or in the observations we make from it, but in the scientific and technological progress that will come in the process of doing it. And much of that will have direct economic and health benefits for those of us who remain behind on Earth."

NASA's Innovative Partnerships Program (IPP) is seeking to be a facilitator and catalyst for innovation in two directions: technology infusion to provide technical solutions to some of the challenges being faced by NASA's programs and projects; and technology transfer—or spinoffs—to provide solutions to non-NASA technical challenges in the private sector or other government agencies with NASA-developed technology. IPP achieves these objectives through a network of offices at each of NASA's 10 field centers.

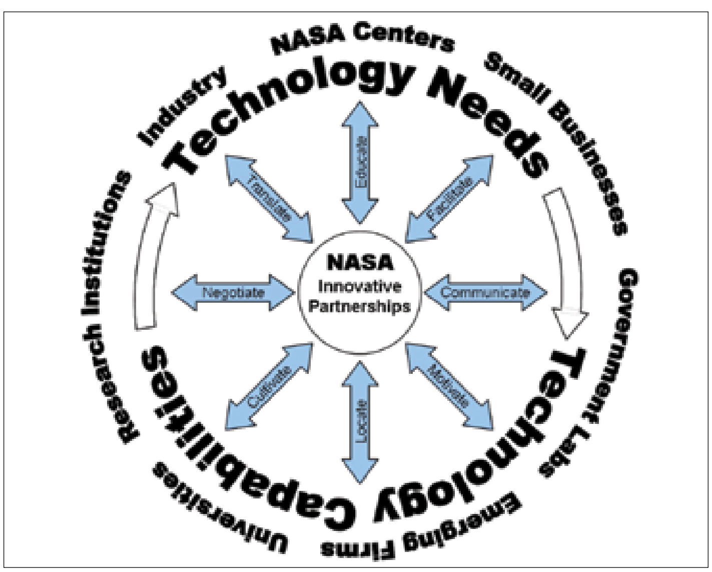


Figure 1. NASA's Innovative Partnerships Program is engaged in a dynamic process to match technology needs with capabilities.

Innovation in this context is not a prescribed process, but rather an ongoing dynamic process with many simultaneous activities and organizations involved, seeking to match technology needs with technology capabilities, as shown in figure 1. In addition to the programs and projects at the 10 NASA field centers, organizations involved include small businesses, other government agencies and their laboratories, emerging firms seeking to address new markets including commercial space, universities and research institutions, and industry.

There are many activities undertaken to support this dynamic process. These activities are critical throughout the lifecycle of a partnership, from the initial state of identifying a need, locating potential sources of technology or innovation to address that need, facilitating the connection between potential partners and the negotiation that leads to an agreement. Once a partnership has been established, it must be cultivated with regular and ongoing communications, and success should be recognized and rewarded to create positive incentives that will continue to motivate innovation.

Communication is a critically important activity in this process. One of the premier tools NASA uses for communicating its technologies that are available for use outside of NASA is *Tech Briefs* magazine (figure 2), which is read by over 250,000 technology experts. Soon, *Tech Briefs* will also be used to feature some of NASA's current and future technology challenges in an effort to reach out to technologists who may have ideas or technologies available that can address those challenges.

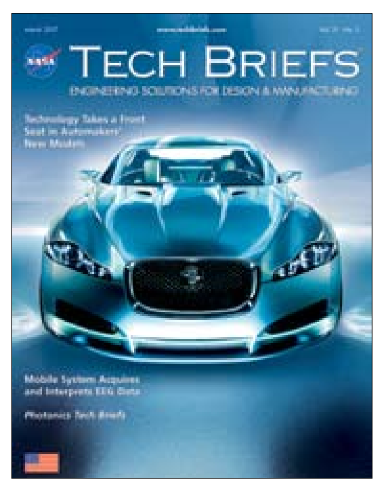


Figure 2. Tech Briefs magazine provides access to NASA's latest technical innovations for over 250,000 advanced technology subscribers.

Communication is also important to convey success stories. This type of communication not only helps advise our stakeholders as to how well we are doing, but also provides important case

Figure 3. NASA's annual Spinoff publication has described more than 1,500 technologies that have been transferred to provide a broad range of societal benefits.

studies and lessons learned to help enable more successes in the future. *Spinoff* (figure 3) is NASA's annual publication featuring successfully commercialized NASA technology. For more than 40 years, IPP has facilitated the transfer of NASA technology to the private sector, improving the quality of life, contributing to US global competitiveness, and stimulating the national economy.

The broad spectrum of NASA technologies has relevance to an even broader range of industrial sectors. For example, successful transfer of NASA technology has led to the development of commercial products and services in the fields of health and medicine, industry, consumer goods, transportation, public health, computer technology, and environmental resources. Since 1976, *Spinoff* has annually featured 40 to 50 of these successfully transferred technologies.

Another important activity performed by IPP is *facilitation*—identifying technological needs, forming relationships and creating opportunities for making connections between sources that can fulfill those needs, through a number of venues. One particular facilitation activity that has been a big success for NASA is the TecFusion Forum. These forums actively reach out to large companies in various industry sectors to connect their needs with technologies developed by small businesses through federal funding, creating partnership and acquisition opportunities.

The *education* of NASA personnel as well as industry and others, regarding the opportunities and mechanisms for partnerships, is a very important element of the dynamic innovation process. An example of this is the authority for government agencies and their prime contractors to contract with small business innovative research (SBIR) firms for continued work on technologies they have developed with SBIR funding. Such contracts can be made on a sole-source basis without competition, enabling rapid access to technologies that may be very important to mission success. IPP also works with small businesses to help them mature their business processes and their ability to be successful.

By surveying the technology landscape inside and outside of NASA, the IPP professionals and their contractor support team are able to *locate* potential matches. To identify technology capabilities that NASA can offer, NASA inventors including civil servants and contractors, file New Technology Reports (NTRs) that describe their new technologies and what the potential applications may be. These NTRs form the basis for technologies that are communicated to a broad audience through the *Tech Briefs* publication described previously.

To identify NASA's technology needs, IPP works closely with NASA's Mission Directorates—the four NASA organizations responsible for investments in flight missions and technical projects to achieve the agencies goals in space exploration, space science, aeronautics and space operations. IPP communicates those needs through an annual solicitation for its SBIR/Small Business Technology Transfer (STTR) program, developed in close coordination with NASA's Mission Directorates, programs, projects and field centers. The annual solicitation is being structured such that SBIR/STTR investments will be integrated with and complementary to other Mission Directorate technology investments. In addition, there are industry workshops and focused activities conducted by the Mission Directorates to communicate their needs and challenges.

The IPP professionals who are seeking to make these connections between needs and capabilities often have to *translate* between different cultures and industrial sectors. Translation is a critical activity in order to avoid missed opportunities. Technologies in one sector may be described in different terms than in another, so it is important to have an understanding of the principles behind a particular technology to fully realize the potential for alternate applications.

In order for any partnership to succeed, getting to an agreement is just the start. It will take ongoing work from both sides in a partnership to *cultivate* the partnership to achieve its objectives.

Figure 4. NASA's Centennial Challenge program seeks non-traditional sources of innovation through prize competitions, such as the Lunar Lander Challenge.

NASA *motivates* the generation of technology by providing direct funding through contracts like SBIR and STTR, but also motivates innovation to achieve technical needs through prizes. Centennial Challenges (figure 4) is NASA's program of prize contests to stimulate innovation and competition in solar system exploration and ongoing NASA mission areas. By making awards based on actual achievements, instead of proposals, Centennial Challenges seeks novel solutions to NASA's mission challenges from non-traditional sources of innovation in academia, industry, and the public.

Another activity to motivate and technology solutions is the IPP Seed Fund—an annual solicitation from the IPP Office to enhance NASA's ability to meet Mission capability goals by providing leveraged funding to address technology barriers via cost-shared, joint-development partnerships. IPP works closely with the Mission Directorates to identify capability focus areas that

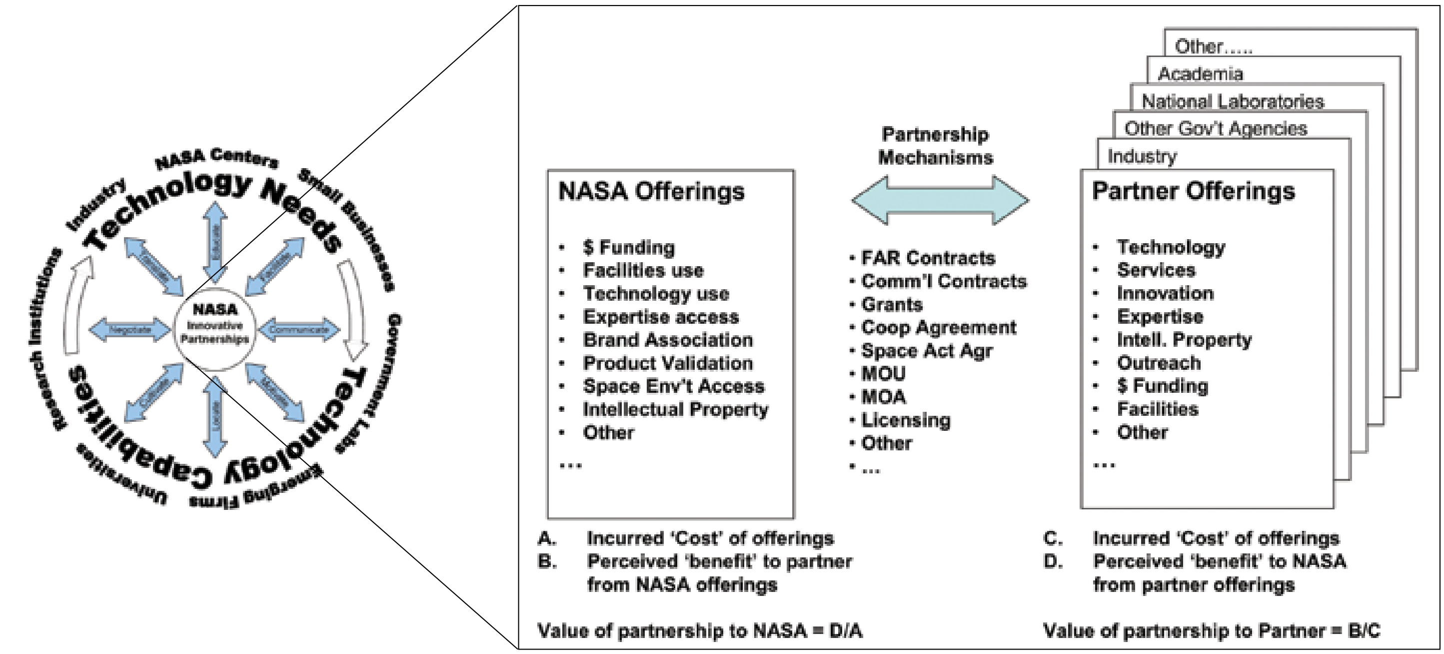


Figure 5. This generalized model of partnerships provides a useful construct for pursuit of partnerships, once the dynamic innovation process has identified potential matches of technology needs and capabilities.

technology investments such as SBIR/STTR, Centennial Challenges, and Seed Fund can address, in order to provide critical needs that are integral to their technology planning and investment strategy.

Creating positive incentives for achieving objectives can be very important to *motivate* success. One of the key mechanisms NASA has for achieving this is the Inventions and Contributions Board (ICB). The ICB, administered by the NASA chief engineer, is a major contributor in rewarding outstanding scientific or technical contributions sponsored, adopted, supported, or used by NASA which are significant to aeronautics and space activities. Over the past 48 years, the ICB has issued over 95,000 awards to NASA and its contractor employees, as well as to other government, university, and industry personnel.

A Generalized Partnership Model

When this dynamic process yields an opportunity for partnership such as a potential match established between a technology need and capability, it is important to *negotiate* an agreement based on the most appropriate mechanism. As part of this negotiation, it is important to understand the various facets of a potential partnership, and the perspectives of each partner. To do this, it is useful to consider a generalized partnership model, as shown in figure 5, that captures the type of offerings that NASA and its potential partners can make.

NASA's offerings could include technology, access to NASA facilities or expertise, and of course funding. Partner offerings could include technology, services, intellectual property, and so forth. There are numerous mechanisms that could be employed to effect a partnership, from licensing to contracts or grants, to space act agreements. NASA has unique authority for partnership agreements—known as Space Act Agreements—as part of the agency's enabling authorization under the NASA Space Act of 1958. This has given NASA a long history of collaboration as part of the agency's mandate.

For a partnership to be successful, each of the partners must

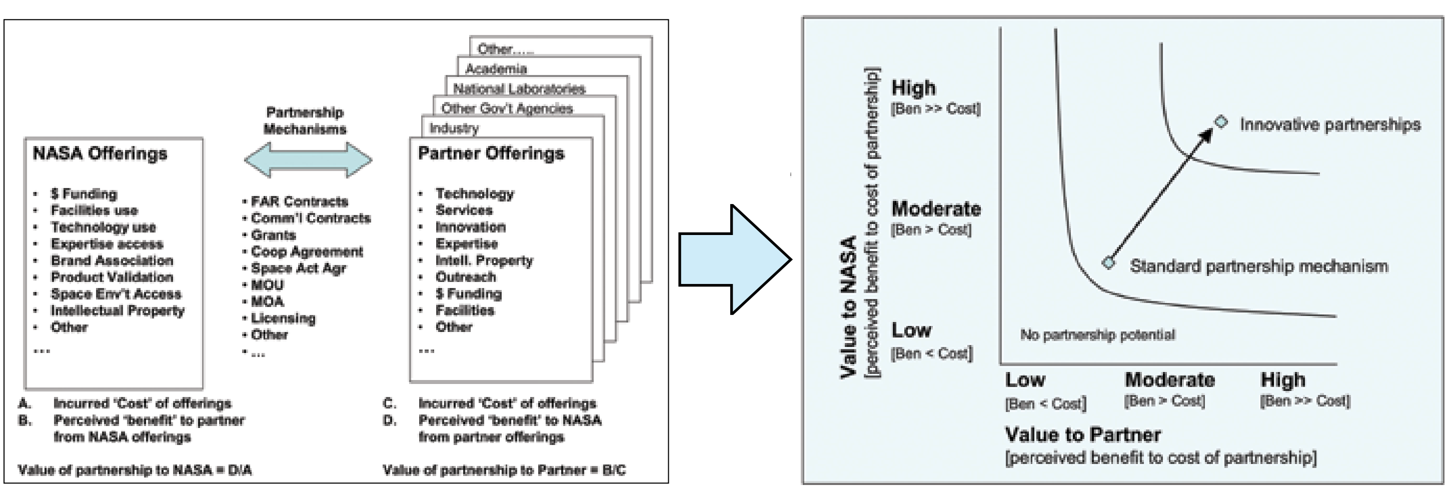


Figure 6. This conceptual value proposition is a useful construct to maximize value for both partners, when formulating a partnership.

perceive that the partnership provides good value, where the benefits derived from the partnership greatly exceed the costs of entering into the partnership. Perception is important here because although the cost of entering into a partnership may be quantifiable in dollar terms, the benefits to be derived from a partnership may not be easily quantifiable. An example could be a partner's interest in using a NASA facility with unique capabilities essential to meet their needs, or the benefit that NASA sees in positive outreach with the public resulting from a partnership.

The Value Proposition

The value proposition for a partnership (based on the partnership model previously discussed) is shown in figure 6. The objective of a partnership is for each partner to derive a high value as a result of the partnership. When putting a partnership in place, it is useful to consider the actions being taken and characteristics of the partnership, then relating those items to the value of the partnership.

It is in the best interest of both partners, for example, to avoid a lengthy and burdensome process of putting a partnership in place. Doing so adds to the cost of both partners, and creates delays that tend to reduce the benefits to be derived, both of which erode value.

Meeting NASA's Technology Needs

As a result of this dynamic innovation process, technology can flow in both directions—into and out of NASA. Technology flowing into NASA can be from a number of sources. One of the biggest sources that IPP is directly involved in is funded research through the SBIR/STTR program. There have been notable successes from this program, with technologies being infused into some of NASA's high profile missions and directly contributing to their success.

Some examples (figure 7) include the Mars Exploration Rovers using lithium ion batteries, ASCII chips and heat switches developed with SBIR funding, and the wireless sensors developed with SBIR funding that are now placed in the leading edge of the Space Shuttle wings to detect possible damage during ascent, as part of the Shuttle return to flight modifications after the Columbia disaster. This latter technology, known as Sensor Control and Acquisition Telecommunications wireless instrumentation systems, has also been used for multiple applications on the International Space Station (ISS) such as wireless vehicle health monitoring, wireless instrumentation and data recording, and for instrumentation of flight tests for developmental vehicles.

Transferring Technology to Benefit Society

Another key output of this process is transferring technologies from NASA for use in new applications that improve the quality of life for the American public. Two examples are given below, and thousands of other examples can be found on the NASA Web site references provided at the end of this article.

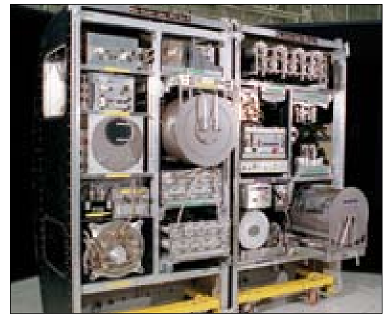
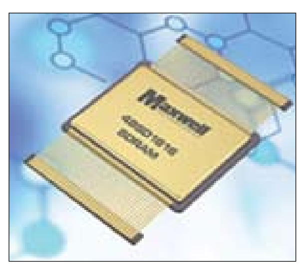


Figure 8. NASA's regenerative ECLSS for the ISS, shown here, has led to devices for turning wastewater into safe, affordable drinking water

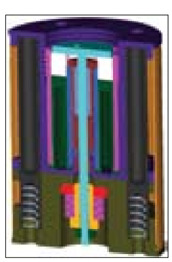
First, a water filtration system (figure 8) providing safe, affordable drinking water around the world is the result of work done by NASA's Marshall Space Flight Center engineers who are creating the regenerative Environmental Control and Life Support System (ECLSS). This is a complex system of devices intended to sustain the astronauts living on the ISS. A derivative of this device is available through Water Security Corporation Inc., of Sparks, Nevada, and makes use of the available resources by turning wastewater into drinkable water.

A second example comes from an SBIR partnership between NASA's Johnson Space Center and private industry to develop technology for autonomous rendezvous and docking of space vehicles to service satellites. This partnership resulted in a new eye-tracking device for LASIK surgery, called LADARTracker. Eye-tracking devices must be able to sample the eye's position at a rate of at least 1,000 times per second to keep up with sac-

Figure 7. Numerous NASA missions, including high profile examples like the Mars Exploration Rovers (MER) and the Space Shuttle return to flight have infused SBIR technologies providing important contributions to mission success.



Maxwell Technologies of San Diego, California *fabricated and tested an ASCII chip with single event latch up protection technology. Innovation enables the use of commercial chip technology in space missions, providing higher performance at a lower cost. Supplying A to D converter for Mars 2003 Rovers.*



Starsys Research of Boulder, Colorado *developed several paraffin based heat switches that function autonomously. Heat switches control radiator for electronics package on Mars 2003 Rovers.*

Yardney Technical Products of Pawtucket, Connecticut *developed lithium ion batteries with specific energy of >100Wh/kg and energy density of 240 Wh/l and long cycle life. Subsequently, they won a large Air Force/NASA contract to develop batteries for space applications. They are supplying the batteries for the 2003 Mars Rovers.*

cadic movements, which do not stop during LASIK surgery. LADARTracker measures eye movements at a rate of 4,000 times per second—four times the established safety margin. The device is manufactured by Alcon Laboratories, of Fort Worth, Texas, and is used in conjunction with the company's LADARVision 4000 system for LASIK surgery, which is being used by eye surgeons across the country.

Figure 9. LASIK eye surgery, as shown here, is now safer due to the use of technology from a NASA partnership.

Summary

The dynamic process described herein provides an illustration of how NASA applies innovation through eight activities, to achieve the dual objectives of matching technology needs and technology capabilities in two directions—infusion into NASA and transfer out of NASA. These eight activities—communicate, motivate, locate, cultivate, negotiate, translate, educate, and facilitate—can be thought of as IPP's innovate eight, or 'innov8'. To learn more about NASA's Innovative Partnerships Program, or to explore potential areas of interest for partnership with NASA, please refer to the following Web sites:

- NASA: www.nasa.gov
- Innovative Partnerships Program: ipp.nasa.gov
- Tech Briefs: www.techbrief.com
- Spinoff: www.sti.nasa.gov/tto
- Centennial Challenges: centennialchallenges.nasa.gov/

IPP Overview

The Innovative Partnerships Program Office (IPPO) provides needed technology and capabilities for NASA's Mission Directorates, Programs, and Projects through investments and partnerships with industry, academia, government agencies and national laboratories. As one of NASA's Mission Support Offices, IPPO supports all Mission Directorates and has program offices at each of the NASA field centers. In addition to leveraged technology investments, dual-use technology-related partnerships, and technology solutions for NASA, IPP enables cost avoidance, and accelerates technology maturation.

IPP consists of the following program elements: Technology Infusion which includes the SBIR/STTR programs and the IPP Seed Fund; Innovation Incubator which includes Centennial Challenges and new efforts such as facilitating the purchase of services from the emerging commercial space sector; and Partnership Development which includes Intellectual Property management and Technology Transfer, and new innovative partnerships. Together these program elements increase NASA's connection to emerging technologies in external communities, enable targeted positioning of NASA's technology portfolio in selected areas, and secure NASA's intellectual property to provide fair access and to support NASA's strategic goals. Technology transfer through dual-use partnerships and licensing also creates many important socio-economic benefits within the broader community.

During fiscal year 2006, the IPP facilitated many partnerships and agreements, including over 200 partnerships with the private sector, federal and state government, academia, and other entities for dual use technology development and reimbursable use of NASA facilities, over 50 license agreements with private entities for commercial and quality of life applications of NASA developed technology, reporting of more than 750 new technologies developed by NASA civil servants and contractors, and evaluation for patent protection, more than 400 agreements for commercial application of software developed by NASA.

Mr. Douglas A. Comstock (BS, Mechanical Engineering, BA, Architecture, University of Washington; MS, Aeronautics and Astronautics, MS, Technology and Policy, MIT) is director, Innovative Partnerships Program (IPP) at the National Aeronautics and Space Administration (NASA) Headquarters, Washington, DC. The Innovative Partnerships Program provides leveraged technology for NASA's mission directorates, programs and projects through investments and technology partnerships with industry, academia, government agencies, and national laboratories.

Mr. Comstock is responsible for directing the IPP portfolio of technology investments and partnering mechanisms including Small Business Innovative Research, Small Business Technology Transfer Research, NASA's prize program of Centennial Challenges, and the Innovative Partnerships Seed Fund. He is also responsible for intellectual property management and technology transfer that will provide broad societal benefits from the nation's investment in NASA's space and aeronautics missions, and for encouraging and facilitating partnerships with the emerging commercial space sector including the agency's purchase of emerging commercial services.

Mr. Comstock previously served as the NASA comptroller, responsible for the preparation, tracking, presentation, and defense of NASA's budget to the White House Office of Management and Budget and the Congress. As the founding director of NASA's Strategic Investments Division, he was responsible for integrating NASA's strategic planning and program analysis supporting budget decisions into a single organization. Under his leadership, NASA was the first agency to achieve GREEN status as part of the President's Management Agenda for Budget and Performance Integration and NASA received its first honorable mention for the President's Quality Award.

Before coming to NASA, Mr. Comstock spent four years as a program examiner in the White House Office of Management and Budget, with responsibility for NASA's human space flight activities, biological and physical research, and personnel. Prior to his government service, Mr. Comstock was director of engineering with the Futron Corporation, a Bethesda, Maryland-based technology consulting firm, and began his career with General Dynamics Space Systems Division in San Diego, California, conducting preliminary design and systems analysis for numerous aerospace systems, from strategic defense to advanced space transportation.

Industry Perspective

Space Superiority in the 21st Century

Mr. Elon Musk
CEO and CTO
Space Exploration Technologies (SpaceX)

If you plot the growth of space capability in China versus the United States, it quickly becomes clear that while China has grown in leaps and bounds, we have flat-lined in manned space for a quarter century and made only a modest improvement in satellite launch with the Evolved Expendable Launch Vehicle (EELV) program. At the national level, we now have a plan to move forward with manned spaceflight through the National Aeronautics and Space Administration Ares/Orion and commercial off-the-shelf programs. The Department of Defense is also establishing an operationally responsive space office, which is a wise move given growing foreign anti-satellite capabilities. However, at present that office only supports the light lift class of unmanned launch, leaving the US vulnerable in the critical medium to heavy lift class.

China can match the US today in medium lift capability, is already superior in price per pound to orbit and continues to innovate at a pace far greater than ours. Extrapolate the trends and it is obvious that unless America improves its rate of innovation, we will be a clear second to China in less than 10 years and India within less than 20.

This is not a matter of speculation. The New Generation Long March medium to heavy lift rocket program under development by China is slated to debut as soon as 2011. It will at least match and may exceed US mass to orbit capability and will be leagues better in price and responsiveness, where they have publicly stated goals of a 20 day launch cycle and a maximum of three days between satellite mate and flight. Some might argue that China can't be beaten in price due to their lower cost of labor, but that does not explain why they remain far from being serious competition in aircraft, computer CPUs, Internet technology, and thousands of other products. American innovation is the real key to staying ahead.

Others might wonder why it matters all that much if another country has lower launch prices than we do. The reason is that whoever leads in price will over time capture the lion's share of the billion dollar plus per year commercial launch market, an amount of money comparable to what we spend on EELV purchases. When combined with their domestic government business, they will have a superior ongoing cash flow to fund innovation and, by virtue of a higher launch rate, greater economies of scale to further extend their pricing advantage. Being on the losing end of the launch business also negatively affects our balance of payments, diminishes our space launch workforce and hurts our economy.

The technology of warfare has always been a race, not a static picture, so it is surprising that many people fail to look even five or 10 years ahead, instead comparing only the present status of our space technology to that of other countries. Unless we take action to improve our rate of innovation in space, we will be unable to avoid falling to second place and being on our way to third as India, which also has a far greater pace of innovation in space than we do, also passes us by. If we do not fundamentally change our approach, then what is today a heavily relied upon strength in the space arena will become a relative weakness in future conflicts.

This is something we would never accept when it comes to fighter jets, unmanned aerial vehicles, or other vital strategic assets and there are developments underway to ensure that the US stays ahead in those fields. With our increasing dependence on the high ground of space, it is no less important to ensure that we also lead in that sector.

This requires a new approach to design, procurement, and operation of satellites and launch vehicles alike. We should also be very cognizant of the fact that, as pressure on the federal budget increases due to baby boomer retirement entitlements, mission cost will matter more and more. Launching billion dollar satellites on multi-hundred million dollar rockets is thus a tenuous long-term strategy, especially when potential adversaries have the ability to neutralize those assets with low-cost anti-satellite missiles.

We must supplement our reliance on today's centralized gigasats with rapid deployment medium sized and smaller satellites, just as a carrier battle group is supplemented by cruisers, destroyers, and other smaller craft. Extending the analogy, today's situation in space would be like having a naval fleet that consisted primarily of a small number of very sophisticated, but slow moving and almost defenseless battleships.

Reducing the cost of missions and flying more frequently will allow planners to tolerate and even encourage the risk-taking that is so fundamental to innovation. As a result, the technology in American satellites will be much closer to our terrestrial state of the art, where we are likely to remain far ahead of the rest of the world. This will also provide a means for the large satellite programs to gain confidence in state of the art technologies at minimal risk.

A Vicious Cycle of Increasing Cost

There is a direct impedance match between the cost of a satellite and the cost of a launch vehicle. When boosters have at least a multi-year lead time and cost well over a hundred million dollars on a fully accounted basis, a satellite program will naturally spend hundreds of millions of dollars on redundancy, mass savings, and packing in as many capabilities as possible. If the instrument misses that ride or the mission fails for any reason, the next flight opportunity is years away.

This results in a vicious cycle of cost increases between the launch vehicle and the satellite. I have heard people say many times that even if the rocket cost was reduced, that wouldn't affect their mission cost all that much, because the satellite represents a majority of the total mission cost. However, what is being overlooked is that the satellite is designed for a world with high cost, infrequent and long lead time launch vehicles.

To get a sense for how much better things could be, consider how much that same capability might cost if it were built for the ground and didn't have to last unattended for a decade. How much does it cost today for a terrestrial telescope with an aperture of that size or a dish of that diameter? The reality is that the technology we have in space is orders of magnitude more expensive and is primitive in almost every respect compared to terrestrial systems. Some of that expense is justified by the high radiation environment and the need to operate in a vacuum, but much of it is not.

If launch costs decreased substantially and flight rate increased, satellite makers could in turn spend much less on mass optimization, redundancy, and ensuring a decade or more of unattended operation. It would also be much easier to justify the risk associated with innovative new spacecraft technologies when the next launch opportunity is months rather than years away.

Unfortunately, current US medium and heavy launch vehicles are not competitive in the international launch market, despite substantial investment by the government. If not for an undersupply of global launch capacity (you read it right, undersupply), exacerbated by the recent Sea Launch failure, US market share in commercially competed launch contracts would go from minimal to zero.

If no competition arises, we should not be surprised to see US launch costs get worse every year and innovation grind almost to a halt, even with the best of intentions. That is historically what happens when competition is removed from any industry.

The only way to improve the situation and increase innovation in the domestic space transportation industry is by encouraging competition, particularly from new entrants. As the great economist Joseph A. Schumpeter initially surmised and was later mathematically shown by Aghion & Howitt, breakthrough innovation almost always comes from new entrants, rather than existing corporations that are weighed down by entrenched business models and legacy cost structures.

The Holy Grail of Orbital Space Launch

The biggest breakthrough in rocketry, arguably since the advent of the Vergeltungswaffe-2, would be an orbital launch vehicle where all stages are reusable and where that reusability is cost efficient. The only launch system in the world with even partial reusability is the Space Shuttle. Unfortunately, with a cost per launch in a good year of roughly a billion dollars (divide its $4.5 billion budget line by the maximum possible number of launches), the Shuttle costs several times more than an expendable rocket of similar payload class.

Consider what would happen if aircraft could only be used for one flight before being discarded. Instead of paying as little as a few hundred dollars for a transatlantic trip in a 747 when it is capable of being flown thousands of times, that same ticket would cost at least three orders of magnitude more if the 747 could only be flown once.

The payload to propellant mass ratio is inherently greater in rockets than in aircraft. However, for rockets that use a low cost fuel like RP-1 kerosene, which is chemically almost identical to jet fuel, combined with an even lower cost oxidizer like liquid oxygen, propellant is still well under 0.5 percent of the total cost per launch. Even assuming a conservative increase in launch rate and far lower reuse efficiency than aircraft, an eventual three to five fold improvement in cost versus a single use expendable rocket should be achievable.

Reliability will also improve with reusability, provided that a commensurate increase in flight rate occurs. As aircraft have shown, practice makes perfect and nothing irons the bugs out of a system more than flying over and over again. Retrieving and examining hardware after a mission is also critical to finding the "near misses" that hurt long term reliability. You may be surprised to learn that traveling in a US airliner over the past five years literally carried lower risk of death than the same amount of time spent sitting in your own house.

A high flight rate also means much more responsive launch capability. Instead of having to plan and purchase launches several years ahead of time, satellites could simply be designed to a well understood set of launch vehicle loads and flown as soon as they are ready.

That is why SpaceX has designed its first generation Falcon 1 light lift vehicle with a reusable first stage and the second generation Falcon 9 medium to heavy lift with all stages reusable. Even without taking reusability into account, a commercial procured Falcon 1 at $7 million and Falcon 9 starting at $35 million are the most cost competitive launch vehicles in the world and represent a three to four fold reduction compared to existing domestic boosters.

As reusability is refined over several years, our models predict that, in 2007 dollars, Falcon 1 flights could drop to $5 million and Falcon 9 flights to $14 million, provided price elasticity drives a doubling of current launch demand. If launch demand remains at current levels, reusability should over the course of several years still drive Falcon 1 below $6 million and a basic Falcon 9 down to approximately $24 million in 2007 dollars. With a third generation improvement in the reusability architecture, such as transitioning from parachutes to a winged first stage, those numbers would drop even further.

While SpaceX has only just completed the test phase for the Falcon 1 launch vehicle and Falcon 9 is slated to do its first test flight next year, the progress to date is cause for measured optimism. For the first time in over a decade, the US has a domestically manufactured launch vehicle that is successfully competing and winning in the global market without burdening the taxpayer.

Mr. Elon Musk (BS, Economics, Wharton School of Business, University of Pennsylvania; BA, Physics, University of Pennsylvania) is the CEO and CTO of SpaceX—the third company founded by Mr. Musk. Prior to SpaceX, he co-founded PayPal, the world's leading electronic payment system, and served as the company's chairman and CEO. PayPal has over twenty million customers in 38 countries, processes several billion dollars per year and went public on the NASDAQ under PYPL in early 2002. PayPal was acquired by eBay in October 2002.

Before PayPal, Mr. Musk co-founded Zip2 Corporation in 1995, a leading provider of enterprise software and services to the media industry, with investments from The New York Times Company, Knight-Ridder, MDV, Softbank, and the Hearst Corporation. He served as chairman, CEO, and chief technology officer and in March 1999 sold Zip2 to Compaq.

Mr. Musk's early experience extends across a spectrum of advanced technology industries, from high energy density ultra-capacitors at Pinnacle Research to software development at Rocket Science and Microsoft.

Space Innovation and the Historical Record: A Messy, Frustrating, and Astonishing Record of Achievement

Dr. Alexis Livanos
Corporate Vice President and President
Northrop Grumman Space Technology

Two thousand seven marks an auspicious year for those of us who have dedicated ourselves to the uses, technologies, and dream of space. This 4 October, mankind will celebrate what is conventionally considered the start of the space age. On that day, fifty years ago, Sputnik became the first manmade object to orbit the earth. Since then, the story of man's quest to place his mark in the vacuum of space has been one of astonishing ingenuity, leadership, and innovation. In anticipation of this anniversary, we can expect many authors to revisit the history of that innovation. Such retrospectives will be interesting. If carefully examined, the history of man's first half century in space will unveil great lessons—lessons relevant to our current efforts at space innovation. To engineers like myself, and others who read this journal, who have spent our careers in the arena of technology development, the lesson most valuable to our current and future efforts is also the one that is initially least inspiring—specifically, that solid, innovative technological development is not enough to make innovative space systems a success.

To see how this is so, and to learn how to manage our technology development programs to better accommodate this reality, a historical review of a few of the watersheds of space innovation is in order. In deference to good science, this thought experiment will benefit from a control group, and one of the best candidates for that purpose is the event we honor this year—Sputnik. It's a good control because Sputnik did not have to contend with the other obstacles and "speed bumps" common to technology programs in free societies (i.e., legislative oversight, budgetary restrictions, and others that we will examine in detail momentarily). As the product of a "command" governmental system, the pace and progress of the Sputnik program was restricted only by it's technological challenges once the patronage of the system's top leadership (in the person of Premier Khrushchev) was secured.

As an almost purely technology driven, "low-drag" program, Sputnik achieved its intended purpose—the making of a geopolitical statement—in a manner out of all proportion to the state of its own technology. It shocked the world and horrified the western democracies even though the technology of its R-7 rocket was primitive. Compared to its competition on the other side of the world, however, Sputnik proceeded at a lightning pace. Here in the US our rocketry was primitive too, but even more challenging to the pace of our program were the inter-service rivalries, turf fights between the military and the National Research Laboratory, debates between scientists and engineers, budgetary restrictions, and even personality differences. After the success of Sputnik, Werner von Braun stated that his team could have beaten the Soviets into space by a year were it not for these extraneous burdens. His testing record with the Redstone and Jupiter missiles supports his conjecture.

As von Braun learned over five decades ago, in America innovative technology is not sufficient to see a program through to deployment. Our research and development (R&D) environment was, and is, messy, complicated, frustrating, and "high drag." Properly channeled and harnessed, it is also without peer in producing the finest technologies in the world.

So, how to channel and harness our cacophonous system? If innovative technology is not enough to get a system from the laboratory to the consumer, what else is required? The answer has its origins in the thinking done as recently as the 1990s during the debates over the revolution in military affairs, and military transformation. In short, many of the thinkers of those debates concluded that technology development is not neat and linear.

Technology represents only one leg of a three-legged stool. In addition to technology, the utility of the stool also requires two other legs—organizational innovation and innovative doctrine. The second leg, organizational innovation, means building a culture that supports new technology within customer, stakeholder and user communities. It's a tough job, but essential to ensure the steady funding required for innovative systems to be brought online within a reasonable timeframe and cost. The third leg of the stool, innovative doctrine, refers to the way technology is utilized. It's the instruction manual. War fighters need adequate training to use new technology to its best advantage. All three must be managed in concert starting as early as possible in the program's development to maximize the implementation. Let's look at some more history.

Global Positioning System

One need not be a theatre commander or strike planner to appreciate the value of the evolutionary constellation of positioning and navigation satellites collectively known as the global positioning system (GPS). There can scarcely be a person alive today who has not benefited from GPS, which makes it all the more amazing for the layman to learn how difficult it was for the system's early supporters to win effective support for the program.

But difficult it was. Though the system's potential did not dawn on the world at large until the First Gulf War in 1991, the program's advocates had been predicting its importance for years before that. As early as 1979, Lt Gen Richard Henry, USAF, stated publicly that the implications of the technology "are so staggering that the strategic and tactical doctrine of our fighting forces will be re-written." Yet between the program's birth in 1973 and the First Gulf War the program had several deaths and resurrections for a wide range of reasons few of which originated in the technology itself. Reasons such as the program not being joint enough, initial lack of interagency support; changing priorities among some of its intended military consumers; congressional annoyance at cost increases and schedule slippages; and initial unfamiliarity with space-based navigation (or as one wag facetiously characterized it, "Real men use maps.").

The journey of GPS from the lab to the customer, and the consumer, offers a case study in how organizational and doctrinal (or policy) obstacles can endanger the most innovative technology. A 1981 Senate Authorization Report noting GPS's importance astutely explains how it is that good technology is so often not enough.

> It may be difficult to understand the full potential [of GPS] until the system is deployed and the vast number of potential users are able to see what it will do for them. [If] for short-term budget limitations [GPS's] potential is compromised or deployment delayed, it will be difficult for potential users to plan for and rely on the availability of what could be a major step forward in weapon systems effectiveness.

In other words, as good as the technology might be, organizational obstacles in procurement, acquisition (or for that matter, understanding and cultural acceptance), budgetary instability, and so forth, will deter users from formulating the doctrine necessary to make use of it. And such organizational and doctrinal obstacles will, in turn, erode support for the technology.

The GPS story offers lessons on how to ensure that all three legs serve the same purpose. First, we do well to accept that the full potential of truly transformational space innovation is likely to be unknowable. This suggests the need for program managers to work for the education and familiarization of the intended consumers and decision-makers on the potential of the technology.

Second, that outreach should include education (focused especially on our legislative appropriators) on the nature of R&D—specifically that R&D is not possible without difficulties, obstacles, and setbacks.

Third, it is difficult to overstress the importance of a stable resource stream, backed by political commitment. (One of the best manifestations of this is the block buy.)

The fourth lesson is found in the value of starting early to overcome institutional and cultural reluctance. Innovative technologies promise dramatic improvements in capabilities. But new capabilities usually imply a need for new doctrine, tactics, techniques, and procedures—always an enormous undertaking. Operational familiarity with new systems through "real world" experience, exercises, and training is important, and the earlier the better.

For interagency programs, agreement on mission, operational, and system requirements is needed as early as possible. Turmoil in these areas too often results in technical problems, schedule delays, higher costs, and increased political scrutiny.

Tracking and Data Relay Satellite System

The Tracking and Data Relay Satellite System (TDRSS) has been a tremendous success since the first of the system's nine satellites was launched in 1983. For the first time, NASA was able to provide a nearly continuous communication link to low-Earth orbiting (LEO) satellites (to include the Space Shuttle and the International Space Station) eliminating the need for a global network of ground stations. It represented true global connectivity to LEO satellites that previously could only communicate in short bursts. And it created a basic communications infrastructure that no longer depended on the cooperation of foreign governments to host the ground stations. Despite these clear advantages, TDRSS initially met with opposition. Though the manned space program community clamored for this new capability, the "unmanned" program community initially balked at the cost imposition for use of a system they did not anticipate would provide great benefits. In truth, the system of ground stations already in place represented a large capital investment and had served well both manned and unmanned programs. Indeed, they were still serving well by the first launch date in 1983. Abandoning them would require a top to bottom policy and doctrinal make-over for an unknown gain.

In the end, the objections were overcome and most ground stations were phased out. TDRSS proved itself as beneficial to unmanned programs as to manned ones and now serves programs that TDRSS was never envisioned to serve. In fact, it has showered all user communities with benefits and capabilities that were quite unforeseen at the time of inception. The TDRSS story underlines the importance of anticipating cultural resistance and starting early to overcome it. The TDRSS story also highlights the importance of beginning work as soon as possible on the doctrinal and policy needs expected of a new system.

But it also reveals a very human quality; the natural affection for the familiar, especially when the stakes are high and the benefits unknown. One should expect the users of a functioning system to resist making the investments necessary to perform those functions better. The history of so many of the transformational space systems of the past half century, however, consistently shows that if such reservations can be satisfied and that resistance overcome, the pace of technology usually ensures improvement by orders of magnitude.

It will prove interesting to see, years hence, if these lessons will be applied to other transformational space innovations now aborning. One such innovation comes to mind, and so far, the indications are promising.

Transformational Satellite Communications system

What GPS did for positioning, timing and navigation, the Transformational Satellite Communications system (TSAT) promises to do for military communications. Our limited military bandwidth is under severe pressure. Operation "Enduring Freedom" in Afghanistan in 2002, as compared to the First Gulf

War, required multiple times the communications bandwidth for a fraction of the force size. It has been reported that our forces in Iraq must outsource about 80 percent of their communications bandwidth needs to commercial satellites (thus establishing the irony of our troops possibly depending on the same systems for their communications as the terrorists they are trying to find). It is indisputable that these pressures will only increase as more use is made of unmanned aerial vehicles, to name just one fast growing category of bandwidth absorbing technology.

One recent *Air Force Magazine* article characterized TSAT as, "the Holy Grail in military communications capability."[1] Because the laser link technology is so revolutionary, the program might have been expected to suffer the same excruciating "fits-n-starts" developmental history as GPS or other similarly ground-breaking systems. Yet, until recent budget pressures pushed out the program into the next decade, TSAT moved forward with the first launch expected to be within a few short years from the Air Force's requirements definitions in 2004.

One reason has been the Air Force's diligence in working early to anticipate and address Congress's concerns about the state of the technology and the program's costs. They did this through a wise block acquisition approach as well as a willingness to go initially with satellites of less capability. Once in place, TSAT will carry ten times the bandwidth of Advanced Extremely High Frequency satellites, which themselves pass communications at rates five times faster than the newest MILSTAR. At least for now, all three legs, technology, organization and doctrine, are being managed in careful synchronization.

Conclusion

Our system by which we Americans develop, procure and deploy advanced space technology is indeed messy, complicated, frustrating, and high-drag. The pure technophile may pine for the kind of streamlined acquisition system that produced Sputnik—until, that is, he reflects long enough to compare the peerless innovations our messy system has produced with those produced by "command" governments. In our acquisition arena no technology is so innovative that it can indemnify itself against delay or even cancellation. People disagree; interests and equities are argued and negotiated; Congressional appropriator's debate and maneuver among themselves to affect the outcome they believe will best benefit the nation; and service leaders, engineers, and program managers challenge each other, almost always in good faith and with the best intentions. What astonishing advances this messy system of ours has produced over the past half century.

We can take comfort in the knowledge that the three elements of technology innovation, organizational innovation, and doctrinal innovation need not work against each other. Indeed, these three disparate elements can synergize into one effective triad if properly channeled and harnessed. A high tempo of technology development can facilitate the engineering of capability "place-holders" into a system against the day that organization and doctrine catch up. Doctrinal and organizational ground can be prepared in advance of a new system speeding and even encouraging development and deployment.

These are lessons we have learned since 4 October 1957, but we are still only on the first page of the story of mankind's development and use of space and its attendant technologies. The best is yet to come, and our system of technology development, if used properly, and for all its frustrations, is easily the best available to keep our momentum going.

Notes:

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Space Innovation is the Key to Providing Combat Power

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"Everything we do is for the joint fight"[1]
~ General Kevin P. Chilton, AFSPC Commander

Robert Higham and Stephen Harris's recent book, *Why Air Forces Fail: The Anatomy of Defeat* is a collection of essays on air forces in history that were defeated and an in-depth examination of the causes of those failures. While it is a book of history, many of the conclusions transcend traditional air-breathing platforms and offer lessons applicable to space forces. Some of the conclusions will be used through the article to bring a framework to the discussion of why space innovation is key to providing combat power to the warfighter.

It is a paradox of space capabilities that their increased use brings about a transparency that in many ways is welcome, but likewise causes an expectation, and often apathy.[2] Because space systems are not seen after launch, like aircraft sorties, the capabilities they bring are quickly taken for granted. You cannot see stress on a satellite part or touch its overused skin. Yet, due to those very reasons, satellites are more costly per unit and demand continual scientific efforts to maintain those capabilities, not to mention improve upon them.

It should likewise be remembered that this transparency occurs in the civilian commercial sector which multiplies the challenge to military-space systems. As more Americans grow used to their cell phones, fast credit card payment transactions, and on-line banking, these fragile systems and networks become expected.[3] That heavy expectation comes with little recognition of the requirements to maintain and increase those capabilities.

There seems to be a cycle of space capabilities which only increase as space effects become available. This cycle illustrates how the vulnerability is created. Air Force Space Command (AFSPC) leadership is addressing these challenges and seeking to close much of the holes and gaps in space vulnerability.[4]

"… air forces face the weakening complexities of costs and controls and consequent shrinking of their size."[5]

In recent history, traditional military space applications and operations were often viewed as not fully integrated into the joint fight—a closed circuit of capabilities which mattered little to the larger fight. Primarily since Desert Storm, we've turned the corner. Space capabilities are fully recognized as essential to any warfight, whether air, sea, land, or joint centric.

The current fight still seems to be in the area of convincing policy makers of the need for space maintenance and recapitalization.[6] The acquisition of space capabilities, many of them needed "yesterday," is a hot bed of debate and congressional pushback. Even though there is general agreement in the need for greater space capabilities, procuring the dollars remains a challenge.[7] Further, most of the loudest criticism is with the transformational systems such as Space Based Infrared Systems (SBIRS), Transformational Satellite (TSAT), and Advanced Extremely High Frequency (AEHF) system.[8]

Recapitalization of space systems is ongoing, slowly, and we have a long way to go. Developing and fielding revolutionary new capabilities promises to be a difficult task by comparison. But several of those systems promise to be the basis for space situational awareness (SSA)—the essential first step in knowing who is out there, what they're capable of doing and when they're going to do it. SSA is so important; General Chilton has said it "…is going to be key to us no matter what the threat is or what the future holds."[9] As we debate these issues, we all should remember one corollary of space capabilities that runs throughout its history; for a warfighter, the more you get, the more you want.[10]

Today's threats demonstrate more than ever that we will need even more space capabilities. The Global War on Terrorism has exploded the need for many space systems due to a highly mobile, secretive enemy who does not follow legal or moral codes of war and adapts quickly, and incidentally also uses space assets to enable their twisted strategy against the west.

"Underestimating the need, time, or industrial competence or capability required to keep pace with adversaries is a common component of defeat …"[11]

Growing confrontational rhetoric from China and Russia illustrate another avenue that speaks to our need for vastly better capabilities. To view China and Russia's growing military space capabilities as benign to US interest's sells them short and expose an ignorance of recent events.[12] The most troubling and overt act occurred just a few months ago when China demonstrated its anti-satellite capability with tremendous results to a bewildered world. China, not seeming to realize the far-reaching implications of their actions or of the 1,037 pieces of free-floating space debris within weeks called for talks on limitations of space "weaponry".[13] This was despite the fact that Chinese military writings over the past 10 years argues for aggressive pre-emptive attacks and covert deployment of antisatellite weapon (ASAT) capabilities for use in a crisis with the US. No public Chinese military writings disagrees with this hardline position.[14] This type of political double-speak, backed up with military capability and strategic discourse should be viewed for what it is—a warning.[15]

Russia's military resurgence which includes space also demonstrates why space capabilities are a vital national interest of many nations, not just the United States.[16] Within months of the world outrage of the Chinese ASAT test and with such strong statements as Russian Maj Gen Vyacheslav Fateyev calling the test, "hooliganism," a joint space venture was announced between Russia, China, and France.[17] As Russia is the only other country—besides the US—in the world to successfully place humans in space, China stands to learn a great deal in the arena of space capabilities from their new partners.

And as if those threats were not enough, there are even more threats, potentially more lethal, largely unknown threats dealing within the infinite realms of cyberspace and biometrics. Though cyberspace is getting a great deal of attention of late, it remains in its infancy especially with how it relates in the networked world and to space systems.[18]

Our adversaries view our growing reliance on space as one of our greatest vulnerabilities. One they believe can be threatened and negated through asymmetric means. As a nation facing a myriad of threats that change more like a living organism than a linear graph, we continue to act and react without having yet to face a catastrophic event that would provide a clear public appreciation for space capabilities. But the timeline is shrinking. That we continue to capitalize on innovative ideas and strive to get expanded capabilities to the warfighter is nothing new in warfare. Usually the systems we rush to the front tend to be fairly mature like Global Hawk and armed Predators. But in today's world, accelerating highly complex and costly systems comes with increased risk, almost certainly increased cost, and an increased need for space capabilities. Many times the increase in space requirements is an afterthought or assumed in the rush to employ them. The bandwidth requirements alone could heavily task our ability to meet the warfighters thirsty need for space capabilities.

As we face funding shortfalls, increased congressional interest, acquisition challenges, evolving threats from every sphere, budgetary constraints and decreased force structure, one can only ask, "What is the answer?"

It's not in the box, that's one sure thing. But how do we think outside the box at the same time we're getting back to basics?[19]

"The severest test of government is whether, in times of war, it can integrate a viable grand strategy with available resources, manpower, and the nature and vulnerability of both the enemy and its own vital resources, including lines of communications."[20]

One answer is we can only address all of these issues with a mindset change of unparalleled proportions equal to the efforts for Cold War mobilization. Complimenting the mindset change requires a healthy dose of innovation. Innovation is the "act or process of inventing or introducing something new" or more accurately, *"a new way of doing things."[21]* What we in the military consider innovation is generally regarded the later of the definitions … a new way of doing things with minimal new invention required.

There are numerous innovation centers in the military, perhaps too many. With the ever-increasing need to shorten timelines and the overpowering stress of decreasing budgets, the challenge often becomes to gain and defend resources rather than getting results. As the Air Force shrinks, fewer platforms transform into fewer platforms for testing and experimentation which could greatly reduce innovation efforts. Being more open within innovation circles can help in increasing platforms for multiple use as well as breaking down the walls between science projects and true innovation that can rapidly provide weapon capability is the key.

Space capabilities are an often unrecognized, but increasingly central part of military innovation programs.[22] The Army's recent success with the Guided Multiple Launch Rocket System (GMLRS) is just one example. Using satellite guidance on an artillery warhead lobbed over 40 miles to land within 10 feet of its aimpoint with about one minute from time of call to delivery is an innovation dependant on space capabilities.[23]

"Mismanagement of human resources is another major common denominator of defeat and failure."[24]

As we all have heard, a constant challenge of the intelligence community is to discern their products and processes into "actionable intelligence." Likewise, our challenge is to discern "actionable innovation." We can start by realizing we are Airmen first, period. We must get past offering up our Air Force Specialty Code title as the answer to what we do. As Airmen, we are required to be skilled in air power, it's doctrine, history, capabilities, limitations and contributions to the warfight. As space experts working in space, we are expected to be skilled in the doctrine, history, capabilities, limitations, and contributions to the warfight of space but we must go one step further to being the acknowledged experts in space. Some have said our unofficial slogan is "Skilled in air, experts in space." But it's more than a slogan, it's a job responsibility. Further, by investing more operators, warfighters (especially those that have been customers of space capabilities) and others with the right skill set at our innovation centers will go a long way towards realizing capability to the warfighter. Actual experience on the battlefield brings a perspective no other experience can and is especially useful to many space innovation projects. The Space Professional Development Program (SPDP) is properly framing the focus on the need for particular positions requiring certain skill sets for Air Force space professionals across the Department of Defense. SPDP is also working to increase the technical competence of all space professionals. These efforts are beginning to pay dividends with increasing course offerings at the National Security Space Institute and additional efforts for masters degree programs at the civilian and military academic installations.[25] The University of Colorado at Colorado Springs began a new pilot program for a Space Certificate in January 2007 for 20 Space Professionals.

In all of this, we must also keep focus on the end result, "…'unlocking the potential' of our space systems and forging the integration of space into all operations—military and civil."[26] Getting results rapidly to the warfighter should be the innovation focus … period.

"Nobody consciously plans to lose …"[27]

Innovation units and those organizations charged with such activities must be more open to sharing ideas, combining resources, and using their expertise toward the focus of getting the capability to the warfighter. It is in this way that innovation can begin to shorten the lines within the cycle of capability and mitigate inherent space vulnerabilities and ensure space will always provide combat power.

The Space Innovation and Development Center (SIDC) is on the cutting edge of space innovation projects. In conducting the daily mission within the SIDC, expertise covers just about all major Air Force mission areas. From former flying personnel, to space tactics, developers, testers, experimenters—all are key to innovation and all are Airmen.

The SIDC's bread and butter is providing operational expertise to Advanced Concept Technology Developments and Military Utility Assessments. These collaborative initiatives focus on driving advanced innovative ideas to meet the needs of the combatant commanders. A full discussion on the SIDC and many of its projects, partners, and successes are included in this issue on page 13.

But even with so many successes, we must constantly strive and be willing to share and learn from others—we have got to work together—with all the military innovation centers to truly capitalize on the advantage brought by space capabilities and to ensure that no matter how transparent or expected space capabilities may become to the American people, we never let that transparency become so vulnerable that we cannot recover if it is exploited by an enemy.

One clear lesson evolves from the historical failure of militaries, not just air forces … we must not fight the last war … to which should be added, in space policy, funding or capability. A new way of doing things—innovation, may be the answer. In all that we do, we must focus on ***providing combat power*** for the United States. Quite simply, that's what we do as Airmen who are recognized space experts.

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"Conundrum"
90th Space Wing's Training Management Database

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In Air Force Space Command (AFSPC), all mission- and combat-ready crew positions are governed by various instructions, such as AFSPCI 36-2202, Mission Ready Training, Evaluation, and Standardization Programs, and AFSPCI 10-1202, Crew Force Management. These instructions mandate a detailed process to document each crew member's training, evaluations and other requirements in individual qualification folders (IQF). The process of these documentation requirements and the maintenance of IQFs is highly standardized and can represent a critical inspection item during higher headquarters (HHQ) inspections of AFSPC units. As a result, IQFs and training reports represent a critical link in operating AFSPCs weapon systems and accomplishing the Command's diverse missions. However, the dynamic nature of AFSPCs operations, in addition to monthly training requirements, makes it almost impossible to ensure 100 percent accuracy of all records at any time. In order to overcome this limitation, the 90th Space Wing (90 SW) has implemented a networked database system designed to track each crewmember's monthly training completion and levels of performance.

"Conundrum" is a Microsoft Structured Query Language (SQL) database which resides on a Windows NT server.[1] SQL, which is based on the Standard English Query Language developed by IBM for its System R project, was standardized as a database language in 1986.[2] SQL not only provides a means for specifying and modifying database objects, types, and constraints (data definition language), but also for querying and modifying database content (data manipulation language).[3] In addition, SQL is one of the most commonly applied database languages, and even Microsoft Access is based on a version of SQL. However, in order to use data contained in Microsoft Access, every user must have that software available and must be trained to apply the tools.[4]

Conundrum avoids the problems of additional software and training requirements by accessing the SQL database through any computer's Web browser on the 90 SWs local area network (LAN).[5] In conjunction with Microsoft's Active Server Pages (ASP) software, Web browsers access the SQL database and display data to the users as Web pages. ASP is a Microsoft extension to Hypertext Markup Language (HTML) supported by the company's Web servers, and it combines HTML with a scripting language for the Windows operating system.[6] Figure 1 shows the database's network structure.

While this structure provides database and network benefits detailed later in this article, it can be vulnerable to SQL injection attacks. SQL injection attacks consist of hackers' exploiting the programming code used to retrieve database information. By modifying the uniform resource locator in the Web browser's address bar, hackers can use SQL injection to access all database records instead of inserting a password. Since Conundrum is housed on an intranet, the base's firewalls and other network protection measures should prevent hacker access to the database; however, it could be vulnerable to internal threats. To overcome these, careful programming procedures must be applied.

One of the system benefits of SQL and ASP is that these capabilities almost always already exist on Air Force networks and do not have to be purchased separately. Microsoft's ASP software is provided with Microsoft Windows NT and Windows 2000 servers, and most Air Force organizations have acquired the necessary SQL site licenses for use.[7]

"Conundrum" Data Security Measures

According to the System Administration, Networking, and Security Organization Institute, authentication is "the process of determining whether something or someone is who or what it is declared to be. The most common form of authentication is the use of logon passwords."[8] Coupled with authentication is the concept of authorization, which "provides assurance that the user … has been specifically and explicitly authorized by the proper authority to access, update, or delete the contents of an information asset."[9]

For Conundrum, each user is assigned an authorization level within the SQL database. Through these pre-determined levels, users are able to gain only specific access to specific records.[10] The 90 SWs Conundrum administrator sets these access levels by position, such as squadron commander, instructor, evaluator, script writer, and so forth.[11] All crewmembers in the wing can view their own Forms 14, while instructors are the only personnel with permissions to write to the database. Since Conundrum resides on the wing's intranet, personnel are authenticated through their network credentials, and a crew member identifier then provides access to individual data.[12]

Operational Impact

Ensuring the mission readiness of all crewmembers always has been a critical part of Air Force operations, and detailed procedures have been necessary in order to document initial and recurring

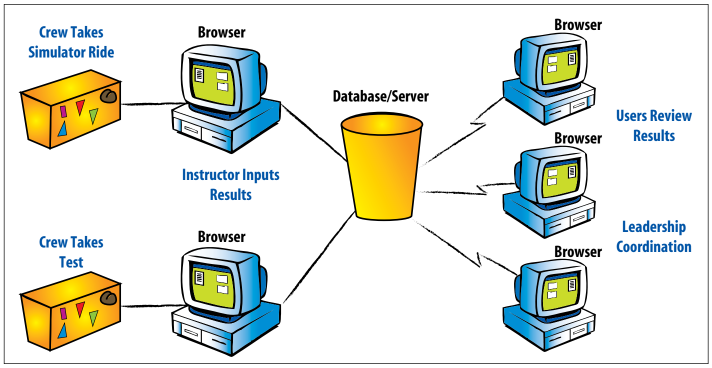

Figure 1. Conundrum "2002 President's Quality Award," Expanded Electronic Government Submission.

training, evaluation, and certification requirements.

Conundrum has enabled the training documentation process to move into the 21st century and has resulted in many advantages in accomplishing the countless documentation requirements for crewmembers. Most importantly is that each one of these benefits directly impact the wing's operational mission. Since crewmembers are not authorized to operate a weapon system without having completed any number of mandatory training aspects, the accuracy of Conundrum's records directly impacts which crewmembers are available to accomplish the mission.

As a minimum, each mission-ready crewmember in AFSPC must complete one training scenario per quarter (usually monthly), which is conducted in a simulator, emulator, or on an operational system based on the specific weapon systems and mission types.[13] After concluding the training session, each instructor documents the crew's performance by completing a Form 14. Not too long ago, this meant each instructor manually completed a hard-copy Form 14, which was reviewed by various squadron personnel, before it was filed in each individual's IQF (usually after several weeks had elapsed). With Conundrum, however, instructors at the 90 SW can use any desktop computer on the 90 SWs LAN to access an electronic Form 14.

This saves time not only in accomplishing documentation requirements in general, but also in preparing the instructors' comments, which will provide valuable training feedback to the crews (while the scenario and crew's actions are still at the forefront of the instructors' minds). Having the ability to provide quick, thorough, and accurate feedback to the crews then provides the ability for these crews to develop further study plans and for instructors to provide additional training, instead of spending time creating legible Forms 14.

Conundrum also incorporates a direct link to training materials on-line. These lesson plans include references from technical orders, training, and performance objectives, as well as detailed discussions to help crews understand a job performance requirement (JPR) in which they may have a deficiency. Crews can accomplish such self-study by reviewing their own Forms 14, which highlight each missed JPR and links to the appropriate lesson plans, or they can access lesson plans as part of their own self- or crew-study plans. This ability provides a dual benefit to the mission—crews have quick and streamlined access to the most current training materials, so they can improve their operational proficiency, while instructors no longer have to spend time finding lesson plans in a separate electronic file and printing them for crews when requested; time which is better spent updating or preparing new lesson plans or providing one-on-one training to crews.

In addition to the aforementioned benefits, Conundrum's database capability can summarize and analyze error rates quickly, which provides instructors with earlier notice that the crewforce could require retraining on a specific task (due to classroom testing and/or simulator scenarios). If the number of errors on a specific JPR within a training period exceeds an instruction-mandated threshold, the entire wing must be retrained on that JPR. It also provides commanders and other operations group leaders immediate feedback on their crews' performance overall and in contrast to the entire wing.

In addition to the capability of reviewing test scores, a squadron's leadership can review crews' simulator performances electronically from their desktop computers via Conundrum.[14] In the past, each individual in the coordination chain would have to wait till a hard-copy training report made its way from one desk to another, whereas now these supervisors can review their crews' operational proficiency whenever they desire. Not only is this information available when and where commanders need it, it also frees up their valuable time by not having to search for forms or request crewmembers' IQFs when questions arise or decisions have to be made.

Another major advantage of this system is that its drop-down menus help prevent data entry errors, which in the past could have resulted in HHQ inspection errors. For example, since each training scenario requires both a crew commander and a deputy crew commander, the Form 14 requires entering names in both fields. The error block containing drop-down menus for JPRs and error codes is invaluable in trend analysis, and Conundrum's database and programming structure provide built-in error prevention for previously common Form 14 errors, such as incomplete data.

Finally, Conundrum provides the 90 SW with a flexible and adaptable database capability. Although the ICBM mission has not changed much since its Cold War days, forms and instructions have. Since Conundrum is based on documenting operational requirements, such as training, it must be modifiable in order to accurately incorporate all HHQ guidance and direction. As discussed earlier, any non-compliance with HHQ instructions can cause inspection errors ranging from minor to critical levels, which can cause far-reaching operational concerns. For significant errors, wings may have to undergo re-inspections, accomplish additional documentation to implement corrective actions, and so forth—all issues that take away from the necessary training time to keep crews operationally proficient. However, through Conundrum's use of ASP, updates and changes can be made readily available without impacting the data in the SQL database.[15] Besides adding to Conundrum's flexibility, this provides a benefit of protecting the vital data which directly supports the wing's operations.

Summary and Recommendations

Since the processes of training and the resultant documentation directly affect the 90 SW's operational mission, Conundrum's benefits provide a corollary mission impact. In addition, this system does more than provide training documentation—it provides training feedback and a venue to improve proficiency; it provides trend analysis to determine if there is a far-reaching operational deficiency, and more.

However, Conundrum still has room for improvement. Because it is easily modifiable, no two systems are alike within AFSPC. As of February 2006, all missile wings in 20 AF (90 SW, 91 SW, and 341 SW) were using similar versions of Conundrum, while the 14 AF space operations wings (21 SW and 30 SW) have their own, tailored versions. Due to budget shortfalls, though, the 21 SW is no longer able to fund its system, and the 30 SWs Conundrum is maintained by a different, independent company. The 50 SW has an entirely different crew force management database structure supported by a third contractor. To alleviate the problem within 20 AF, Kepler Research currently is developing a next-generation Conundrum. The Training, Evaluation, and Management System will incorporate several upgrades, while retaining Conundrum's flexibility and modifiability centralized through one database administrator at 20 AF.[16]

Standardizing this type of database system throughout the Command would provide numerous benefits. For one, the database could be networked throughout AFSPC and be accessible to other units to share training ideas, lesson plans, or to develop a forum for discussing operational issues. In addition, this would result in a standardized system for all the units, so when instructors, evaluators, or other staff who regularly use these databases move to another unit, they would no longer have to be retrained on that system. It also would enable them to use their standardized database knowledge throughout the Command and devote more time to training and executing the operational mission. If a standardized tool were available, it could be technically supported at one location, with one data owner responsible for the overall process.

In addition, it is important to remove the hard-copy IQF requirements from instructions in order to take advantage of Conundrum or other database networks in their entirety. At the 50 SW, for example, the success and benefits of its Crew Force Management Database, CFM 2.0, in accomplishing the wing's crewforce management functions are tremendous. However, implementing CFM 2.0 involved more than automating an existing process—it required a complete overhaul of the entire training, evaluation, and certification processes.

In line with the Air Force's and AFSPCs goals of eliminating stove-piped systems at various levels, though, only one standardized Web-based system should be developed for the entire Command.[17] This type of implementation would be in direct support of the goals outlined in the AFSPC Architecture Campaign Plan and of General Lord's [former AFSPC/CC] vision of: "We recognize the importance of enterprise architecting as the enabling foundation for an integrated, capabilities-based air and space force … we are committed to the long-term benefits."[18] In 2004, a representative from AFSPCs Enterprise Infrastructure and Integration Branch stated that the Air Force Portal's benefits will result in "the eventual migration from [AFPSC] local intranets to the Portal."[19] Therefore, the implementation of a standardized CFM system, such as Conundrum or CFM 2.0, on the AF Portal would generate not only data security, data stability, and other benefits, but it could also place all support responsibilities with Headquarters Air Force. Through this high-level support and compliance with the Air Force's and AFSPC's net-centric visions, AFSPC would no longer have to maintain its own stovepiped information management system and would no longer have to ensure a critical system's sustainability when threatened by endless funding dilemmas, while garnering all the benefits of a standardized crewforce management system.

Notes:

[1] 90 OSS, *Conundrum: 2002 President's Quality Award, Expanded Electronic Government Submission* (Cheyenne, WY: 2002), 5.

[2] Greg Riccardi, *Principles of Database Systems with Internet and Java Applications* (Boston, MA: Addison Wesley, 2001), 147.

[3] Ibid., 14.

[4] Ibid., 178.

[5] 90 OSS, *Conundrum President's Quality Award,* 5.

[6] Riccardi, *Principles of Database Systems,* 209.

[7] 90 OSS, *Conundrum: An E-Business Solution for the Military. Electronic Presentation* (Cheyenne, WY: 2002).

[8] System Administration, Networking, and Security Organization (SANS) Institute, 2005, www.sans.org.

[9] Michael E. Whitman and Herbert J. Mattord, *Management of Information Security* (Massachusetts: Thomson Course Technology, 2004), 8.

[10] 90 OSS, *Conundrum President's Quality Award,* 6.

[11] 90 OSS, *Electronic Message,* 071111ESTFEB06.

[12] 90 OSS, *Conundrum President's Quality Award,* 6.

[13] Air Force Space Command Instruction (AFSPCI) 36-2202, *Mission Ready Training, Evaluation and Standardization Programs,* 3 February 2003, 13.

[14] 90 OSS, *Electronic Message,* 071111ESTFEB06.

[15] 90 OSS, *Conundrum President's Quality Award,* 6.

[16] 90 OSS, *Electronic Message,* 161941ESTJAN06.

[17] AFSPC, *Architecture Campaign Plan, Version 3.0* (Colorado Springs, CO: HQ AFSPC, 2005), 1.

[18] Ibid.

[19] Jenna McMullin, *Portal becoming part of AFSPC virtual operations* (AFSPC News Service, 19 February 2004).

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Major Wood was commissioned as a Distinguished Graduate of the Reserve Officer Training Corps at The University of Texas at Austin in May 1992. Upon completion of Peacekeeper and Minuteman III—Deuce qualification courses as a Distinguished Graduate, Major Wood began her career in ICBM operations and held various instructor and evaluator, as well as Emergency War Order Training positions. She then served in both instructor and evaluator roles at the 5th Space Surveillance Squadron, RAF Feltwell, UK, followed by an assignment in Current Operations and Special Plans and Programs at Headquarters, Third Air Force, RAF Mildenhall, UK. Major Wood then became chief, Arms Control Branch at US Central Command, MacDill AFB, Florida. Throughout her various roles, Major Wood has gained deployment experience in Africa, Italy, and at the forward-deployed USCENTCOM JOC. Prior to assuming her current position, Major Wood completed in-residence Intermediate Developmental Education as a Distinguished Graduate and was recently selected for promotion to lieutenant colonel.

Learning Space by Doing Space:
Education, Training, and Professional Development Innovations at the United States Air Force Academy

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Over 50 years of evolving innovations in space education, training, and professional development across the academic and military training mission elements of the United States Air Force Academy (USAFA) have coalesced into a truly unique set of broad-based space experiences throughout the four-year undergraduate curriculum for the 4,000-plus cadet wing, many of whom will become our future Air Force senior leaders and key decision makers. Our graduating cadets are now more space savvy upon entering their Air Force careers than ever before. Through a diverse combination of classroom, research, training, and operational facilities, along with a broad spectrum of faculty space expertise across multiple academic departments and disciplines, each cadet has the opportunity to learn fundamental knowledge about space systems, the space environment, and space policy. Cadets are exposed to the physical and mathematical fundamentals of satellite motion, communications, precision navigation and timing, terrestrial imaging, space weather, and astrodynamics. They directly participate in satellite design, development, and operations. The relationships among politics, policy-making processes, law and technology as they relate to the civil, military, commercial, and intelligence space sectors; and national space power, to include roles, missions, doctrine, military operations, and battlespace effects are also explored. Additionally, summer programs for both cadets and faculty in space operations, research at world-class facilities across the United States, and operational and acquisition experiences with Air Force Space Command (AFSPC) units, the Air Force Research Laboratory, the National Reconnaissance Office, the National Aeronautics and Space Administration, and industry partners complement and enhance the Academy's integrated space capabilities. For those cadets who want to pursue Air Force space careers or who have chosen one of the Academy's space-related academic majors, they graduate with thousands of hours of academics, training, and real-world Air Force experiences focused on space.

A very recent innovation is our newly formed Space Programs Council (SPC). The SPC provides policy, planning, guidance, and oversight for all space activities at USAFA, interfacing with the dean of faculty, the faculty council (made up of all academic department heads and permanent professors), the commandant and commandant's staff, and the superintendent's staff. The SPC consists of colonels from the stakeholder organizations (Departments of Astronautics, Economics and Geosciences, Military Instruction, Physics, Political Science, and the commandant's training staff), meeting once per semester to provide direction to members of the Space Working Group (SWG) who execute USAFA space programs and submit budget and other resource requests. The SWG, in turn, meets monthly, and includes representatives from all stakeholder organizations.

Academically, USAFA offers space-related majors in Astronautical Engineering, Astronomy/Space Physics, Applied Physics-Space Vehicle Design, Space Operations, and Space Systems Engineering. The Academy's core curriculum includes an introductory course in astronautics (Astronautical Engineering 310) taken by all cadets, regardless of major, usually in their first-class (senior) year. Additional space course work covering an extensive breadth of topics is offered by the departments of Chemistry, Economics and Geosciences, History, Military Instruction, Physics, and Political Science. Additional details of two of those programs are included below, while specific aspects of the integrated and highly collaborative space curriculum and experiences lead by the Astronautics and Physics departments at the Academy to appear in subsequent journals.

Recently, space education, training, and professional development were added as options for cadet summer programs—in a fashion similar to the existing glider (soaring) or free-fall parachuting (jump) programs—with the establishment of SPACE 251. SPACE 251, a 10-day indoctrination to space taken by 250+ cadets following their fourth-class (freshman) academic year, consists of classroom discussions and activities on space topics, hands-on experiences in various space mission areas, and tours of local space units. In keeping with the leadership model established for our soaring and jump programs, basic ground station operations (SPACE 251) is taught by upper-class cadets who have completed ground station certification training (SPACE 350) and instructor/evaluator upgrade training (SPACE 461).

In addition to the academic and training departments involved in space, several research centers and laboratories contribute to USAFA space education, training, and professional development:

- Academy Observatory Complex

- Center for Space and Defense Studies (CSDS)
- Laser and Optics Research Center
- Space Operations Education Laboratory
- Space Physics and Atmospheric Research Center
- Space Systems Research Center

Of noteworthy significance is the fact that these centers and complexes, along with the USAFA academic departments, are all located such that it is a less than ten minute walking distance between any two areas, thus greatly facilitating extensive collaboration between faculty members, center directors, and cadets.

The Center for Space and Defense Studies

Approximately a year and a half ago, the Academy established the Center for Space and Defense Studies (CSDS) to better integrate thinking about space into teaching defense policy issues to cadets and other young professionals—expanding cadet education about the importance of space to the nation into other fields of study.

Although a variety of teaching resources regarding the space environment, systems, and operations may exist in the basic sciences and engineering fields, little comparable work has been done to define the intellectual foundation for explaining how national policy regarding space is made by the United States and it is in turn shaped by the interests and actions of other countries. The first initiative under the CSDS was the development of a textbook, *Space Defense Policy*, designed for the beginning graduate or senior undergraduate level. This entirely new text consists of thirteen chapters and two appendices, one of which serves as a concise primer in the scientific and engineering background for space systems and the environment in which they operate. Contributing authors include senior faculty at the Academy, civilian universities, military professionals, and analysts from the private sector.

Part of the Academy's model for developing previous books of this type on American defense policy and comparative defense policy involves bringing together the right community of scholars and experts to produce the text and provide peer review and comment to improve and refine it. For the *Space Defense Policy* book, we convened a conference to draw this group together and move the process forward. This first event became our inaugural Forum on Space and Defense, held in January 2006 in Colorado Springs. Each chapter of the upcoming book was made the discussion topic of a panel involving the author and outside experts, with all participants in the event providing comments and suggestions. This past year, the CSDS collaborated with National Defense University (NDU) to present NDU's spacepower theory project to the wider community. As it moves toward its third year, the forum will continue to bring an uncommon blend of professionals from the military, civilian government, higher education, think-tanks, and the private sector to discuss space policy issues.

To foster ongoing discussion, research, and learning about space policy, the CSDS is beginning to produce its own scholarly journal, *Space and Defense*, and sponsors one-day workshops on specific topics such as China's space strategy (June 2006) and space situational awareness (September 2006). The journal's first edition addresses America's role in space and includes open source surveys of major issues in space policy for the United States, European Union, Russia, and China. Future journals will address weapons in space, private operators, and continue following the rise of other space powers such as China.

Programs such as these produce educational resources to improve the quality of education for cadets, and extend beyond the classroom to include experience in research and internship. Last year the CSDS supported cadet research projects looking at the formation of a new national space policy and co-production of the RD-180 engine, an independent study pairing an engineering major with a political science major to write a collaborative paper. This summer the CSDS will bring cadets from the service academies together with students from MIT and George Washington University in the first Summer Space Seminar, a two week program held in Colorado Springs and Washington, DC, introducing some of the nation's best students to the challenges and opportunities presented in space studies.

All of these efforts have been made possible only by the collaboration and material support received from the US Congress, Office of Secretary of Defense, AFSPC, and private gifts to the Academy through the Association of Graduates. By continuing to pair this vital external support with the energy and interest of our cadets, the CSDS seeks to play its role in helping ensure future Air Force officers begin their careers with the education to sustain America's role in space.

The Space Operations Education Laboratory

The Department of Military Strategic Studies (MSS), Dean of Faculty, USAFA, in collaboration with AFSPC, designed, developed, and created a state-of-the-art Space Operations Education Laboratory (SOEL) for USAFA cadets to experience space operations from a multi-disciplinary perspective. This brand new facility officially opened its doors on Thursday, 16 March 2006. Creating this innovative environment found its roots in the vision of early air power leaders.

Genesis of the creative and innovative nature of the Air Force's involvement in space earnestly began with General Henry "Hap" Arnold's appreciation of the relationship between science and technological development. Desiring to capitalize upon the advanced scientific developments spawned by the Second World War, Arnold commented that "the long-haired professors … [need] … to give us a Buck Rodgers program to cover the next twenty years," a program capable of deterring and defeating any potential aggressor. In expressing this desire, Arnold sought to fulfill what he believed was a national need, in this case a combat air force that applied strategy, theory, and doctrine commensurate with advanced technological capabilities. Arnold's insight reflected a nuanced understanding of the potential power of knowledge created to knowledge applied, and later, a youthful protégé named Bernard A. Schriever, created the foundations of today's AFSPC by achieving what Arnold had dreamt.[1]

Jacob Neufeld, historian, observed that Schriever desired to combine "operational requirements with technologies and strategies to establish objectives for future systems." In essence, he sought a synergy between identified and predicted security needs with an educated officer corps capable of employing the best weapons that American scientists and engineers could produce.

Today, this intellectual tradition is alive and well not only among the highly motivated and trained professionals of space command but also within the Department of Military Strategic Studies (DFMI). The Department's mission is to *develop professional Air Force officers schooled in the context, theory and application of military power across the spectrum of conflict*. The officers so educated become lifelong independent learners dedicated to the creative innovative thinking essential to sustaining American strength and vitality.

The mission of the SOEL is to provide a first-class, state-of-the-art facility to integrate space wargaming and simulation, to develop true space professionals who conceptualize space capabilities and missions, and have critical hands-on experiences that simulate space applications. The vision of the SOEL is to complement the cadet space educational experience through the integration of space wargaming and simulation. Utilized by superb educators, these resources supply the Air Force with newly commissioned second lieutenants well versed in the importance, application, strategy, and theory of space as an element of national power consistent with the vision of Generals Arnold and Schriever.[2]

The SOEL simulates active duty missions using unclassified data processing that allows students maximum interaction. Its design is flexible enough to use actual programs from active duty missions and unclassified simulations, maximizing student interaction with real-world experiences. Currently, the SOEL employs Analytical Graphics, Incorporated's Satellite Tool Kit (STK) software. STK is a leading commercial-off-the-shelf analysis software for land, sea, air, and space. Because of its capability to present results in both graphical and text formats, STK makes it easy for our cadets to analyze and determine optimal solutions for complex national security and space scenarios.

STK uses multiple two and three dimensional displays to help cadets visualize space-related objects such as launch vehicles, missiles, and aircraft. STK's core capabilities include orbit/trajectory ephemeris generation, acquisition times, and sensor coverage analysis for any of the objects modeled in the STK environment.

Its capability to connect to secure sites when appropriate, makes the SOEL the perfect location for faculty and cadet research dealing with space operations issues. With its ability to present up to eight screen displays simultaneously, using two one-gun, four-way projection, along with 25 networked PCs integrating Web, digital and analog video and graphics, this environment allows cadets to visualize and comprehend space operations.

Within the classroom and simulation environment, MSS educators develop future leaders capable of an agile mental response to the dynamic world of space thought. Perhaps most important, all cadets graduate from the Academy with a foundational understanding of space. Every cadet must enroll in two core courses that integrate space theory with combat operations. Within these mandatory core courses, MSS 100, Military Theory, Strategy, and Officership, and MSS 400, Joint and Coalition Operations, cadets participate in multiple lessons designed to pyramid such that they develop a sound understanding of the space role in military operations across domains.

The department offers majors courses and electives in which cadets rigorously examine the fundamentals of space strategy, theory, and operations within the context of the American strategic culture and environment. In addition, department curricula assay the intellectual foundations of foreign space powers, including China, Russia, and Europe.

In MSS 382, Air, Space, and Information Power Theory, educators challenge their students to innovate beyond current doctrinal boundaries through critical analysis of air, space, and information power theory to achieve an integrated understanding of Air Force operational domains. This course offers a challenging study of Everett C. Dolman's strategy of "astropolitik," a realist approach to space strategy, and its ramifications for the Air Force. The innovative and transformational heritage of the Air Force space role highlights MSS 462, The Theory of Military Innovation. MSS 485, Space Operations and the Warfighter, examines the intellectual traditions of American space power as contextualized within case studies emphasizing a Clausewitzian framework. Cadets critically examine the role of space power within doctrine, policy, and national security strategy and pursue contemporary and future relevance to Air Force transformation, current operations, and AFSPC's long-range planning. In each of these three courses, cadets critically evaluate leading positions and prepare two-day presentations on a research topic of their choice.

The SOEL provides countless possibilities for the future. A few ideas currently being considered include the following: (1) networking the SOEL with DFMI's existing Warfare Simulation Lab and Air Warfare Lab to provide cadets with a simultaneous view of the strategic, operational, and tactical aspects of war; (2) collaborating with other departments at the Academy to demonstrate a satellite's life cycle: from requirements, to feasibility studies, to environmental analysis, to spacecraft design resulting in an operational on-orbit satellite; (3) continually adding new software capabilities and programs used in the operational Air Force to enhance and expand cadet learning experiences and educational challenges; (4) integrating war-gaming into the SOEL to provide cadets critical-thinking case study challenges allowing them to examine what-ifs of the future.

The lineage of Air Force space owes its success to many, but one man, General Bernard A. Schriever, deserves a closing comment. Schriever remarked that "although we've been working on space capabilities for almost half a century now, progress has not matched the air development in the first half of this century." This is particularly true of the military arena, in which the general believed, "we ignore the proliferation of missile and space technology to our peril." As Schriever recognized, the problem is not technological; it is intellectual. In the Department of Military Strategic Studies, we strive to develop the intellectually curious officer who will rigorously attack and solve these problems for our Air Force and our Nation.[3]

Other Activities

A number of other events and activities throughout the year also support space education, training, and professional development, including the annual USAFA "Space Mixer" that introduces first-class cadets assigned to the space and missile career field to active duty space professionals. Cadets who are space enthusiasts can join USAFA's Space Club (regardless of major and typically during their fourth-class and third-class year) and are provided numerous opportunities to explore space interests. Each spring the commandant sponsors a Basic Space Awareness Day wherein all our third-class cadets hear from a senior space professional leader and are offered a look at civil and military space missions.

Local AFSPC organizations (Headquarters AFSPC and the 21st and 50th Space Wings, in particular) actively support the Academy by providing reviewing officials for cadet presentations, offering facility tours, mentoring cadets in capstone courses, supporting events like the Space Mixer, and training cadets in our summer programs. In fact, the Academy's satellite ground operations are fashioned after those of the 2nd Space Operations Squadron.

Summary

As we have briefly articulated, for the past 50 years space has been, and is even more so today, a central tenet of the entire set of studies and activities experienced by the 4,000-plus cadets throughout their four-year USAFA undergraduate academic and military program. The space opportunities afforded our students is unrivaled by any other four-year institution. With the ongoing space-related innovations across our departments and the recent establishment of the USAFA SPC, which will guide our future USAFA space investments and allocation of resources, we will continue to produce better educated and better prepared future air and space leaders for our Air Force. It is imperative that we do so if we are to remain the world's greatest air and space power!

Notes:

1 John W. Huston, ed., *American Airpower Comes of Age: General Henry H. "Hap" Arnold's World War II Diaries,* vol. 2 (Maxwell Air Force Base, AL: Air University Press, 2002), 367. Arnold wrote this entry, dated Friday, 13 July 1945, while in Paris enroute to a stay at Berchtesgaden, Germany, the site of Hitler's mountain top retreat; Dik Alan Daso, *Hap Arnold and the Evolution of American Airpower,* Smithsonian History of Aviation Series, ed. Von Hardesty (Washington, DC: Smithsonian Institution Press, 2000), 196-197.

2 Jacob Neufeld, "General Bernard A. Schriever: Technological Visionary," *Air Power History* 51 (Spring 2004): 39-40; Stephen B. Johnson, *The United States Air Force and the Culture of Innovation: 1945-1965* (Washington, DC: GPO, 2002), 59-116.

3 Peter L. Hays et al, eds., *Space Power for a New Millennium: Space and US National Security* (New York: McGraw-Hill, 2000), vii – viii.

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Book Review

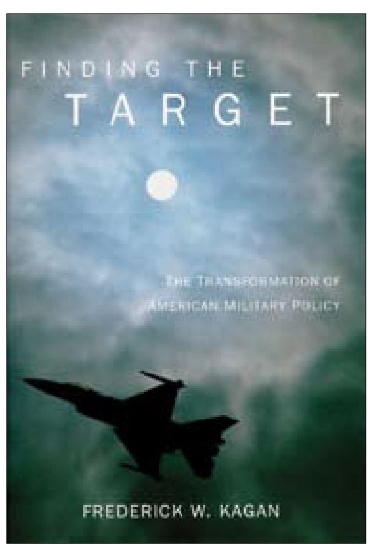
Finding the Target: The Transformation of American Military Policy

Finding the Target: The Transformation of American Military Policy. By Frederick W. Kagan. New York: Encounter Books, 2006. Notes. Bibliography. Index. Pp. xx, 444. $29.95 Hardback ISBN: 1-59403-150-9

In the 1990s, it seemed almost impossible to find any American military literature not peppered with buzz words like "dominant," "precise," "agile," "focused," "synergistic," "system of systems," and "power of information." So says, Yale-educated policy analyst Frederick Kagan in *Finding the Target*. A larger problem, in his opinion, was how writers crammed those particular terms into generally ill-defined, frequently misinterpreted concepts labeled "transformation" and "revolution in military affairs" (RMA). Kagan struggles to clarify, both intellectually and historically, the origin, meaning, and relationship of those broader concepts. He believes their misapplication by many senior leaders, military and political, during the "strategic pause" between the end of the Cold War and the beginning of the Global War on Terror contributed significantly to flawed policies and undesirable strategies—to the American military's unprecedented ability, for lack of clear political objectives, to win the fight but lose the war.

A resident scholar at the American Enterprise Institute and former professor of military history at the US Military Academy, Kagan begins his treatise with an examination of the military services' recovery from Vietnam. Faced with low morale, widespread expectations of a "peace dividend" following the end of hostilities in Southeast Asia, the shift to an all-volunteer force, and expansion of Soviet military power, America's armed forces initiated extensive reforms in the 1970s that led to revolutionary changes in training and doctrine. Those reforms succeeded remarkably in revitalizing America's military posture, because they directed change at specific geostrategic and technical challenges, placed high value on diversity—different ways of solving critical problems—and took advantage of a "narrow sliver" between off-the-shelf and leap-ahead technology.

In the 1980s, President Ronald Reagan's administration and US military leaders completed the transformation begun in the 1970s by concentrating on development of a new, grand strategy to meet the massive Soviet threat and, thereby, win the Cold War. The president, in a period of apparent fiscal constraint, nonetheless increased the defense budget sufficiently to erase critical deficiencies in the armed forces' day-to-day preparedness; he also managed to deploy the new Peacekeeper ICBM and undertake the Strategic Defense Initiative. At the same time, intellectual breakthroughs—John Boyd's OODA-loop concept, and John Warden's "centers of gravity," "five rings," and "parallel war" concepts—fostered a revolution in airpower theory, with the notion at its core of using airpower alone to achieve a war's political objectives. Improvements in "stealth" and "precision strike" technologies created a bridge from those ideas to real-world operations.



According to Kagan, the 1991 Gulf War marked a "turning point" that had both positive and negative consequences for the development of American force structure. An inflated interpretation of airpower's contribution to the outcome of that conflict, combined with inter-service budget battles in the fiscally constrained post-Cold War environment, drove both Air Force and Army leaders down undesirable intellectual paths. Consequently, RMA discussions in the 1990s suffered fundamentally from focusing on warfare in the abstract without considering geo-strategic realities. The absence of clear military threats left transition from an "industrial age" to an "information age" as the only intellectually coherent basis for American military transformation. This, in turn, encouraged a shift from "threat-based" to "capabilities-based" strategic planning, plus an unhealthy fascination with ideas like "shock and awe" and "network-centric warfare." American war-making, Kagan concludes, became essentially a "targeting drill" without consideration of political objectives. The results are apparent currently in Afghanistan and Iraq.

To avoid similar, future outcomes in this age of international terrorism and "regime-change" wars, Kagan recommends adherence to principles set forth nearly two centuries ago in Carl von Clausewitz's *On War*. Planning for war should be from "back to front"—from the desired political outcome to combat operations—not the other way around. Military professionals should give less thought to acquiring new systems to defeat abstract enemies and more to the interaction between the military programs of potential enemies—China, North Korea, Iran, Pakistan, and elsewhere—and American military development. America's future challenge will not be finding new systems to keep the "precision-strike RMA" going but, rather, to find new ways of defeating enemies who are acquiring capabilities nearly equivalent to our own. Beyond that, civilian and military leaders alike should remember always that war is about purposeful violence to achieve political goals.

Finding the Target is a remarkable explication of the complexities surrounding American military thought since the Vietnam War. This does not mean, however, that the analysis is flawless, nor does it mean the book lacks evidence of its author's neoconservative biases. Even looking long and hard at every page of Kagan's book, space professionals will find next to nothing about their realm's influence on military transformation. Last but not least, rereading Bernard Brodie's classic *War and Politics* (1973) for comparative purposes might prove instructive.

Reviewed by Dr. Rick W. Sturdevant, deputy command historian, HQ Air Force Space Command

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